S. HRG. 100-499

BLEACHING OF CORAL REEFS IN THE CARIBBEAN

HEARING

BEFORE A

SUBCOMMITTEE OF THE COMMITTEE ON APPROPRIATIONS UNITED STATES SENATE

ONE HUNDREDTH CONGRESS

FIRST SESSION

SPECIAL HEARING

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BLEACHING OF CORAL REEFS IN THE CARIBBEAN

TUESDAY, NOVEMBER 10, 1987

U.S. SENATE,
SUBCOMMITTEE ON COMMERCE, JUSTICE, STATE,
THE JUDICIARY AND RELATED AGENCIES,
COMMITTEE ON APPROPRIATIONS,
Washington, DC.

The subcommittee met at 10:03 a.m. in room S–146, the Capitol, Hon. Ernest F. Hollings (chairman) presiding.

Present: Senators Hollings and Weicker.

NONDEPARTMENTAL WITNESSES

Damage to Tropical Coral Reefs

OPENING STATEMENTS OF SENATORS HOLLINGS AND WEICKER

Senator HOLLINGS. These hearings will focus on what is perhaps an unusual topic for the subcommittee, that is, the bleaching of tropical corals. As you are all aware, Senator Weicker and I share a longstanding commitment to managing and conserving our marine resources. Thus, I readily agreed when my good friend from Connecticut brought this matter to my attention and asked that we examine it closely.

I understand that coral bleaching recently has been observed in coral reefs throughout the Caribbean and have had serious consequences for the tropical marine environment in that region. Several potential causes have been suggested, ranging from natural temperature variations to manmade pollutants.

While this phenomenon raises serious research and management questions for the Caribbean area, it also raises larger concerns regarding the overall health of our coastal marine environment. Last summer, hundreds of dolphins washed up on the beaches of the East Coast of the United States. Although researchers are still studying the cause of that dolphin epidemic, initial findings indicate that one contributor may have been poor coastal water conditions. Closures of beaches to swimming and shellfish beds to harvesting have also become common occurrences in recent years.

The need for such actions provides a grim reminder that if we do not understand and protect our marine resources, we almost certainly will lose them.

PREPARED STATEMENT

I include the remainder of my statement in the record as if presented.

[The prepared statement of Senator Hollings follows:]

OPENING STATEMENT OF SENATOR ERNEST F. HOLLINGS

Today's hearing will focus on what is perhaps an unusual topic for this subcommittee, the bleaching of tropical corals. As you are all aware, Senator Weicker and I share a longstanding commitment to managing and conserving our marine resources. Thus I readily agreed when my good friend from Connecticut brought this matter to my attention and asked that we examine it more closely. I understand that coral bleaching recently has been observed in coral reefs throughout the Caribbean and may have serious consequences for the tropical marine environment in that region. Several potential causes have been suggested ranging from natural temperature variations to man-made pollutants.

While this phenomenon raises serious research and management questions for the Caribbean area, it also raises larger concerns regarding the overall health of our coastal marine environment. Last summer, hundreds of dolphins washed up on the beaches on the east coast of the United States. Although researchers are still studying the cause of that dolphin epidemic, initial findings indicate that one contributor may have been poor coastal water conditions. Closures of beaches to swimming and shellfish beds to harvesting have also become common occurrences in recent years. The need for such actions provides a grim reminder that if we do not understand and protect our marine resources, we almost certainly will lose them.

A national commitment to a strong marine research program is an essential step toward such understanding and protection. To that end, I sponsored and worked for the passage of a new strategic research initiative as part of the National Sea Grant Program reauthorization. Senator Weicker and I have also struggled for years to see that funds are authorized and appropriated for the research programs of the National Oceanic and Atmospheric Administration. I look forward to today's testimony to provide insight into the coral bleaching problem and also to provide direction for dealing with the larger issue of coastal and marine research.

OPENING REMARKS OF SENATOR WEICKER

Senator HOLLINGS. It is a pleasure to work with Senator Weicker and have these witnesses appear this morning. We have struggled for years for funds for NOAA, as you well know, Lowell, and I am sure this testimony here will help us substantiate even again the needs that we have in the NOAA budget.

Senator WEICKER. Mr. Chairman, thank you very much, and I especially thank you for agreeing to hold these hearings and for all the help that you have given over the years to NOAA, to its budgets, and to the cause of marine research. I think that Senator Fritz Hollings from South Carolina really deserves the lion's share of the credit in the way that the budget for this particular agency and this particular cause has moved forward.

PREPARED STATEMENT

I have got a prepared statement that I want to place in the record.

[The prepared statement of Senator Weicker follows:]

OPENING STATEMENT OF SENATOR LOWELL WEICKER, JR.

Good morning and welcome to today's hearing.

This morning we will be hearing from three panels of witnesses concerning a phenomenon of considerable importance: the bleaching of coral reefs in the Caribbean.

While they are perhaps best known for their decorative properties, corals play a key role in the marine ecosystem. They serve as a wave break for the islands and coasts they border upon and provide critical habitat for fish and other forms of ocean life.

Bleaching occurs when corals lose or slough off a symbiotic algae which has the function of removing waste materials from its host. In the absence of this algae, the corals are killed by their own wastes which, containing nitrogen, bleach the coral to an unnatural white.

Observers from Colombia to Bermuda began noticing the current bleaching event toward the end of this summer. While it is not the first time this phenomenon has been noted—it happened throughout large areas of the Pacific and in the Caribbean in 1983—the current case is distinctive and disturbing because of its geographic range, the number of coral species affected, and the depth and speed at which it is occurring.

We will be looking at this episode in the light of other similar occurrences, including the near-total mortality of tropical sea urchins throughout the Caribbean in 1983–1984 and the dolphin kills along the eastern seaboard of the United States this summer. We still don't know why these deaths took place. A closer look at the coral crisis may help provide some answers.

We hope this morning to document the severity and the significance of the bleaching, its possible causes and the potential for a scientific response based on international cooperation.

DIADEMA KILL IN CARIBBEAN

Senator WEICKER. I want to make the following comments. I don't think that these matters which we are witnessing are isolated.

Several years ago I think the record will show that in some of the questioning of NOAA officials in the presentation of their budget, I asked for explanations of the Diadema kill that had taken place throughout the Caribbean, which literally wiped out what is commonly referred to as sea urchins, the whole sea urchin population. Nobody really came up with a satisfactory answer to that. That was several years ago.

Now, as I understand, Diadema are re-establishing themselves in the Caribbean a very little bit, but that was an extraordinary event, and it went almost unnoticed, at least as far as the public was concerned.

I sort of tucked it away in the back of my computer, and all of a sudden somebody calls me and tells me about what is going on vis-a-vis the coral, and I have to think that maybe there is some connection here with what is happening to the ecosystem.

I know these things may be unrelated, because the Caribbean isn't the Jersey coast. But obviously I have to think about the dolphin kill, and all of a sudden, this coral event, and then I pick up a newspaper and I see a little chit about a huge part of Antarctica's ice shelf breaking off because of rising temperatures or something of that nature.

Obviously, something is going on here where, if we don't get a handle on and have some sort of knowledge of it, what are now isolated instances which we can live with could very well develop into an overall tragedy that we may not be able to live with. I think the time to address this subject is now.

I know many of the panelists that are here today, and I am sure that we will get the best thinking on the matter. With that, let's get to it.

INTRODUCTION OF WITNESSES

Senator HOLLINGS. Before I introduce these witnesses, they have already been introduced, of course, I would like to know why this is occurring, apparently in a more intense form. Yet we have been, now 20 years, onto this environmental pollution control on our own harbor down there in Charleston, and we closed the oyster shells beds in Charleston Harbor in 1926. We opened them up in 1976, because we got pollution, sewage treatment and everything else like that, and that has occurred in many other coastal towns. It seems like rather than going backwards, we would be going forward. That is what nonpluses me.

The first panel will give us a brief introduction of the bleaching event, of its initial discovery. The witnesses are Mr. Robert Wicklund, Director of the Caribbean Marine Research Center and Professor Robert Dill, Professor of Geology at the University of South Carolina, in Columbia, SC.

Senator WEICKER. I have tried to get Senator Hollings to join us on the ocean floor but he has had a tough time with cataracts.

I have spent more time with these two guys on the ocean floor than in the atmosphere.

Dr. DILL. You have.

Mr. WICKLUND. I agree.

Senator HOLLINGS. All I need is a mask. I don't want my lenses to float away that I have got right now.

Senator WEICKER. Notice he didn't ask for an air tank.

Senator HOLLINGS. I carry my own. [Laughter.]

I can get as far as I am getting now.

Dr. DILL. Senator, for you, I will carry you back.

Senator HOLLINGS. My weight is seven and a half right now on the belt. I am ready to go. Do they grind these kinds of lenses in the mask? Do you have them?

Dr. LANG. I have them.

Senator HOLLINGS. Get me one of those, and I will go right back down.

Dr. DILL. If you give us your prescription, you can go right down.

Senator HOLLINGS. Thank you for chairing this hearing. I have to go back.

Senator WEICKER. The floor is yours, gentlemen.

Panel 1

CARIBBEAN MARINE RESEARCH CENTER

STATEMENT OF ROBERT I. WICKLUND, DIRECTOR, CARIBBEAN MARINE RESEARCH CENTER

TIMELINESS OF HEARINGS

Mr. WICKLUND. Mr. Chairman, it is indeed an honor to appear before this committee to discuss the recent incidence of mass stressing and possible mass mortalities of tropical Atlantic coral reefs on the Caribbean and the Atlantic waters.

Before I present my statement I would like to commend the committee on the speed and timeliness of this hearing. The apparent problem with the coral reefs in the Atlantic and Caribbean was just recently discovered and is progressing rapidly. Too often, events such as this are addressed only after the fact. This hearing will hopefully serve to foster and focus efforts to discern exactly what is happening and what the effects will be on tropical and subtropical marine ecosystems.

Tropical coral reefs are some of the richest marine ecological systems in the world. Basically, the coral reefs are oases in the tropical seas, and surrounding water does not support much life.

Corals are also some of the most fragile animals in the sea, readily responding to environmental stresses and disturbances. The health of the coral is one index of the general health of the oceans, particularly in the tropics.

CORAL BLEACHING IN AREA OF LEE STOCKING ISLAND

On October 1, 1987, Dr. Dill, who is beside me today, and I discovered massive bleaching of several species of corals off Lee Stocking Island in the Bahamas. Additionally, we observed soft corals, fire corals and at least three species of sponges and a sea anemone that were bleached. Bleaching occurs when stressed corals or other animals lose all or part of their color-producing zooxanthellae from the soft tissue. This algae lives mutually with the coral and provides food and oxygen, and corals are dependent on them for survival.

The extent of the bleaching or stress is not totally known. We examined 20 miles of coastline and found the effects from 2 feet down to 240 feet.

OTHER AFFECTED AREAS IN CARIBBEAN

Since our initial discovery of bleaching at Lee Stocking Island and adjacent areas, we have been in contact with several persons around the Caribbean area, particularly Dr. Bert Williams with the University of Puerto Rico, and have had reports of bleaching from each of the following locations: Columbia, Puerto Rico, Virgin Islands, Cayman Islands, Jamaica, Bahamas, Haiti, Florida, Bermuda and the Gulf of Mexico. I heard recently that other islands are now being affected.

Considering the geographic range of known coral and other invertebrate bleaching from Central America to Bermuda, it is likely that it is affecting most of the reefs in this general area.

The event that we are addressing here is far more extensive than has ever been previously reported in the tropical Atlantic. Past local bleaching that could be readily attributed to heavy rains was nothing close to what we are seeing today.

MORTALITY OF LONG-SPINED DIADEMA

It brings to mind the Caribbean-wide mortality of the long-spined Diadema, which you mentioned before. In 1983, during the same time the Diadema problem was presented, there was similar, widespread coral bleaching and mortality in the eastern Pacific and Indian oceans and will be described by later witnesses.

Mr. Chairman, the mass bleaching of Atlantic coral reefs is frightening, particularly considering its extent and range and the little information that is available. If the corals that have been observed bleaching die, then we could have a problem on our hands that could have a profound effect on the ecology of most of the marine life dependent on the reefs in the Caribbean and Atlantic.

If we add up all of the mass mortalities of the past years, such as the Pacific corals, the sea urchins, the corals, sponges and other animals we are seeing now, we have to ask ourselves: What is happening? Are the tropical oceans imperiled? Is it cyclic? What are the causes, a virus, pollution, El Niño?

We really don't know. The Pacific kill was directly attributed to warm water resulting from the El Niño effect in 1983. It is possible that this is also the present problem in the Caribbean. We have temperature measurements from the Bahamas that show warmer-than-normal temperatures for this year.

ASSISTANCE NEEDED FROM FEDERAL GOVERNMENT

Regardless of our present theories, the fact remains that we do not really know what is causing the corals to bleach, and the problem needs to be addressed immediately, while it is occurring, not later, when it has run its course. Our Center and several other places in Puerto Rico, Jamaica, Virgin Islands and Florida have small studies, but the magnitude of the problem requires a much more concerted effort which can only be accomplished with help from the U.S. Government in terms of scientific resources and funding.

This is truly an international problem with far-reaching implications. If the bleaching is related to climatic change, then we must study long-range global ocean and weather interactions. This is real important. If it is a man-induced disease, then we must know where it originated and how diseases such as these can be prevented. Rapid and constant communication between nations and scientific personnel is absolutely necessary.

I suggest a study begin as quickly as possible, and I will submit the studies for the record without going over them now for the sake of brevity.

Mr. Chairman, as you know I am not an alarmist. However, when events such as coral stressing occurs, we must take notice. Just recently I read an article that indicated that the greenhouse effect could, in the near future, raise the Earth's mean temperature 3 to 4 degrees Fahrenheit, dramatically affecting our environment. I am not suggesting that this is part of the greenhouse effect, but to draw a parallel, if temperature is a cause of the coral bleaching, then we are already seeing how a small change can affect a vital ecosystem over a large area of the ocean.

We may be forced to recognize that the fragile seas hold the key to understanding the overall health of our planet.

[The prepared statement of Mr. Robert I. Wicklund follows:]

PREPARED STATEMENT OF ROBERT I. WICKLUND

Director
Caribbean Marine Research Center
100 East 17th Street
Riviera Beach, Florida 33404

Mr. Chairman, it is indeed an honor to appear before this Committee to discuss the recent incidence of mass stressing and possible mass mortalities of tropical Atlantic coral reefs in the Caribbean and the Atlantic waters.

Before I present my statement I would like to commend the Committee on the speed and timeliness of this hearing. The apparent problem with the coral reefs in the Atlantic and Caribbean was just recently discovered and is progressing rapidly. Too often events such as this are addressed only after the fact. This hearing will hopefully serve to foster and focus efforts to discern exactly what is happening and what the effects will be on tropical and subtropical marine ecosystems.

Tropical coral reefs are some of the richest marine ecological systems in the world. Their productivity is among the highest in the sea and they provide both shelter and food to a vast array of marine life, including finfish and invertebrates. Their importance to life in the tropical seas is more evident when contrasted with the surrounding water which is virtually sterile and supports little life. The clear waters of the tropics contain few nutrients to support phytoplankton, the base of the oceanic food chain. Coral reefs are oases in the tropical desert seas.

Corals are also some of the most fragile animals in the sea, readily responding to environmental stresses and disturbances. Significant mortalities occurred in the Florida Keys, for instance, as a direct result of dredging and other polluting human activities. Corals in many other

places such as the Bahamas and Caribbean nations are also affected by pollution of one kind or another. The health of corals can be one index of the general health of the oceans, particularly in the tropics.

On October 1, 1987, Dr. Robert Dill, associate researcher of the Caribbean Marine Research Center and adjunct professor at the University of South Carolina, and I discovered massive bleaching of several species of stony corals off Lee Stocking Island, Exuma Cays, Bahamas. Additionally, we observed gorgonian soft corals, fire corals, at least three species of sponges and a sea anenome that were bleached. Bleaching occurs when stressed corals or other animals lose all or part of their color-producing zooxanthellae from the soft tissue. Zooxanthellae are algae that live mutually with the coral, providing food and oxygen, and corals are dependent on them for survival.

The extent of the bleaching or stress is not totally known. We examined 20 miles of coastline in the Exumas in which the corals were affected. We found stony corals affected from depths of 2 feet to 200 feet, sponges affected from 80 feet to 240 feet and soft corals affected from 35 feet to 180 feet. The results of our examination are summarized in Table 1.

Table 1. Animals Observed Bleaching off Lee Stocking Island, Exuma Cays, Bahamas, October 1 - 10, 1987.

Common Name	Scientific Name	Depth Range (ft)
Common Brain Coral	*Diploria strigosa*	3 - 45
Depressed Brain Coral	*Diploria labyrinthiformis*	3 - 45
Staghorn Coral	*Acropora cervicornis*	3 - 45
Clubbed Finger Coral	*Porites porites*	3 - 85
Large Star Coral	*Montastrea cavernosa*	10 - 100
Lettuce Coral	*Agaricia spp.*	3 - 170
Boulder Coral	*Montastrea annularus*	10 - 100
Fire Coral	*Millepora spp.*	3 - 45
Tube Sponge	*Aplysina spp.*	80 - 200
Tub Sponge	*Xestosponia muta*	90 - 180
Loggerhead Sponge	*Spheciospongia sp.*	150 - 170
Sponges (2)	Unidentified	120 - 240
Gorgonians	Unidentified	45 - 180
Sea Anenome	Unidentified	45 -

Since our initial discovery of bleaching at Lee Stocking Island and adjacent areas, we have been in contact with several persons around the Caribbean, particularly Dr. Bert Williams with the Department of Marine Sciences at the University of Puerto Rico, and as of November 10, 1987, have had reports of bleaching from each of the following locations: Columbia, Puerto Rico, Virgin Islands, Cayman Islands, Jamaica, Bahamas, Haiti, Florida, Bermuda and the Gulf of Mexico (Flower Gardens).

Considering the geographic range of known coral and other invertebrate bleaching from Central America to Bermuda, it is likely affecting most of the reefs in the Caribbean and tropical Atlantic.

The event that we are addressing here is far more extensive than has ever been previously reported in the tropical Atlantic. Past local bleaching that could be readily attributed to heavy rains or dredging was nothing close to what we are seeing today.

It brings to mind the Caribbean-wide mortality of the long-spined sea urchin (Diadema) in 1983-1984 which has had dramatic effects on the reefs. Without the urchins to graze them algae grow uncontrolled, competing with and sometimes killing corals. Unfortunately, we never really found the cause of the sea urchin kill.

In 1983 similar wide spread coral bleaching and mortality occurred in the eastern Pacific and Indian Oceans and will be described by later witnesses.

Mr. Chairman, the mass bleaching of Atlantic coral reefs is frightening, particularly considering its extent and range and the little information that is available. If the corals that have been observed bleaching have already died, it could have a profound effect on the ecology of most of the marine life dependent on reefs in the Caribbean and Atlantic. If we add up all of the mass mortalities of the past five years, such as the Pacific corals, the sea urchins and now the corals, sponges and other animals in the Caribbean and Atlantic Ocean, we have to ask ourselves: What is happening ? Are the tropical oceans

imperiled ? Is this a trend ? What about other places where symptoms are not easily seen ? What are the causes ? A virus ? Pollution ? El Niño ?

The Pacific kill was directly attributed to warm water resulting from the El Niño effect in 1983. It's possible that warm water is also the cause of the present problem in the Caribbean. We have temperature measurements that indicate warmer-than-normal temperatures in the Bahamas throughout the spring, summer and fall of 1987. The mechanism for warm water influx into the deep areas in which we saw bleaching (240 feet) does exist off Lee Stocking Island. In July 1986 I observed warm, high-salinity (40 ppt) water cascading over the edge of the shelf during outgoing tides. This water came from the adjacent shallow bank area where evaporation raised the salinity and density of the outflowing water.

Regardless of our present theories, the fact remains that we do not really know what is causing the corals to bleach and the problem needs to be addressed immediately while it is occurring, not later when it has run its course.

Our Center has already initiated a small study of the coral bleaching problem and will continue to monitor the corals around Lee Stocking Island. Other equally small studies in Florida, Jamaica, Puerto Rico and the Virgin Islands are also being conducted. The magnitude of the problem, however, requires a much more concerted effort which can only be accomplished with help from the U.S. Government in terms of scientific resources and funding.

This is truly an international problem with far reaching implications. If the bleaching is related to climatic change then we must study long-range global ocean and weather interactions. If it is a man-induced disease then we must know where it originated and how such diseases can be prevented. Rapid and constant communication between nations and scientific personnel is absolutely necessary.

I suggest that a study begin as quickly as possible to determine the actual extent of the problem and its effect on the ecology of the tropical Atlantic coral reefs. This would include the following work:

1) Catalogue the distribution of all affected species;
2) Set up stations throughout its range to follow the fate of the corals;
3) Attempt to trace the origins of the problem, if possible;
4) Study the immediate and long-term effects of coral stressing on other members of the reef communities;
5) Check historical records for past bleaching and effects;
6) Study all historical and present environmental data for the affected area, including coring of coral reefs to determine similar past events.

Mr. Chairman, I am not an alarmist. However, when events such as the coral stressing occur we must take notice.

Just recently I read an article that indicated the greenhouse effect could, in the near future, raise the earth's mean temperature 3-4 F, dramatically affecting our environment. I'm not suggesting that the problem we are discussing is a result of the greenhouse effect but, to draw a parallel, if temperature is the cause of the coral bleaching, we are already seeing how a small change can affect a vital ecosystem over a large area of the ocean.

We may be forced to recognize that the fragile seas hold the key to understanding the overall health of our planet.

UNIVERSITY OF SOUTH CAROLINA, DEPARTMENT OF GEOLOGY

STATEMENT OF DR. ROBERT F. DILL, PROFESSOR, DEPARTMENT OF GEOLOGY, UNIVERSITY OF SOUTH CAROLINA, COLUMBIA, SOUTH CAROLINA

CARBONATE ENVIRONMENTS

Senator WEICKER. I am going to wait and ask that you both testify, and then we will go to questions.

Dr. DILL. Fine. I am Robert Dill, and I am a marine geologist. You might wonder why a marine geologist is here talking about a problem that one normally considers to be in the realm of the biologist. But I am a carbonate geologist, and as it turns out, most of the major limestones that form on earth and about 60 percent of all the rocks we look at are made of limestone, and the limestones, of course, are part of biology, and they derive their origin from organisms.

As such, I have been studying coral reefs now for about 30 years. Between 1975 and 1981, I was the director of the West Indies laboratory in St. Croix, and, as you will see, two of my former colleagues are giving presentations here later. As such, I have been able to acquire a background in the biology and the nature of reefs. Starting in 1984, I began working with Rob Wicklund on Lee Stocking Island, where he was setting up the Caribbean Marine Research Center. One of the things we have done is look at the different environments in that region and studied them in detail so that we can take students and also professional geologists down to this area so they can better understand carbonate environments.

This has allowed us to see most of the coral reefs in that area, and we have been able to put together a fairly good TV and other underwater photographic coverage of what these environments are. We have published a guidebook for the region based on our research. This gives us a fairly broad background of changes and conditions over the last 4 years of what has happened in that particular area, probably in more detail than normally exists at any other tropical marine laboratory.

PHOTOGRAPHING LEE STOCKING AREA

In July of this year, 1987, I was off Lee Stocking with some students studying and taking photographs of the lush reefs that are in that area. The reef corals were normal. I would like to stress that this area of the Bahamas is a relatively pollution-free region. There are no large population centers. It is not a region that has pollution as you might expect it around a large population center. In July, there was no bleaching.

I went back in September, and I was appalled to see that most of the major head corals species had turned white and the leafy corals had also turned white. I immediately brought this to the attention of Bob Wicklund, and we both went out and started systematically looking at the region. In areas where we knew that we had normally had extremely healthy and beautiful corals, we found that they were all bleached and they did not have their zooxanthellae.

Later, the biological panelists will be able to give you a little bit better background on what their function is in the way of corals, but bleaching normally means that corals are badly stressed. You couldn't actually see or feel what was causing this stress. It was frightening to see that areas that were normally quite lush are now bleached white.

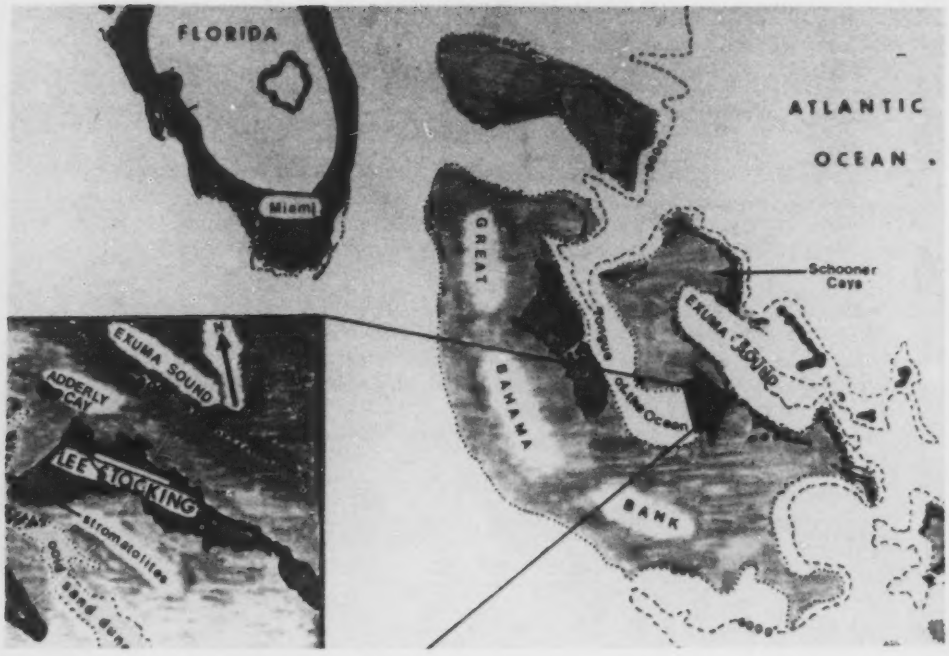
BLEACHING PROBLEM WIDESPREAD

We then have made contact with our other friends in the coral reef community, and found out that this is an extremely widespread problem. When I speak to you today, I don't speak just for myself, but for several of my colleagues. A number have called and talked to me and said that, "We want to be included in the hearings or provide information because we have something to contribute." My testimony includes their concerns. I would like to specifically mention Eugene Shin and Harold Hudson, who work for the U.S. Geological Survey in Florida who have done a considerable amount of coral reef studies over a long period of time. They have the capability of being able to take scores of corals and actually determine their growth rates and whether or not they have been stressed. These gentlemen want to work very closely with us on this problem.

Other people who aren't here today are Phil Dustin, who is at the University of Charleston, who has also been working on the coral reef problem and the problem of bleaching. I bring these two groups to mind because they have made a very strong contribution and have given us the distribution of bleaching that we will be able to present in our testimony.

PRESENTATION OF ILLUSTRATIONS

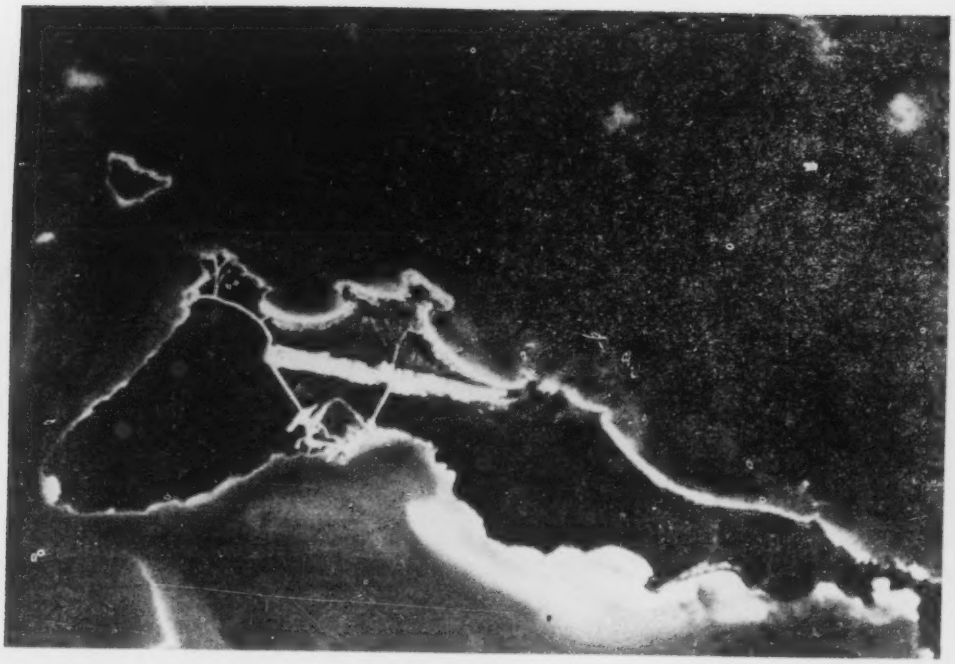
What I would like to do now is show you some underwater photographs of the areas and what bleaching actually looks like. I will turn on the projector.



SLIDE 1

BAHAMAS AREA

The first slide is a map of the Bahamas. To give you an idea of where we are talking about, the black arrow points to Lee Stocking Island. You can see it is on the edge of the deep Exuma Sound. This area is covered by oceanic water, which flows on and off of the Great Bahama Bank every 6 hours in the form of tidal currents.



SLIDE 2

AERIAL VIEW

This slide shows what the area looks like from the air. If you notice the little black lines on the top of the screen, in this area, here and here, these are coral reefs. You will see some underwater photographs of these later. This dark area is a dropoff into deep water. It starts at about a depth of 90 feet.

SLIDE 3

BLEACHED CORALS

This slide shows Bob Wicklund in a coral sea. Note the white patches. They are bleached corals.

SLIDE 4

AFFECTED GORGONIANS

This slide shows more of the corals. Note the gorgonians on the right. These are normally a deep brown color.

SLIDE 5

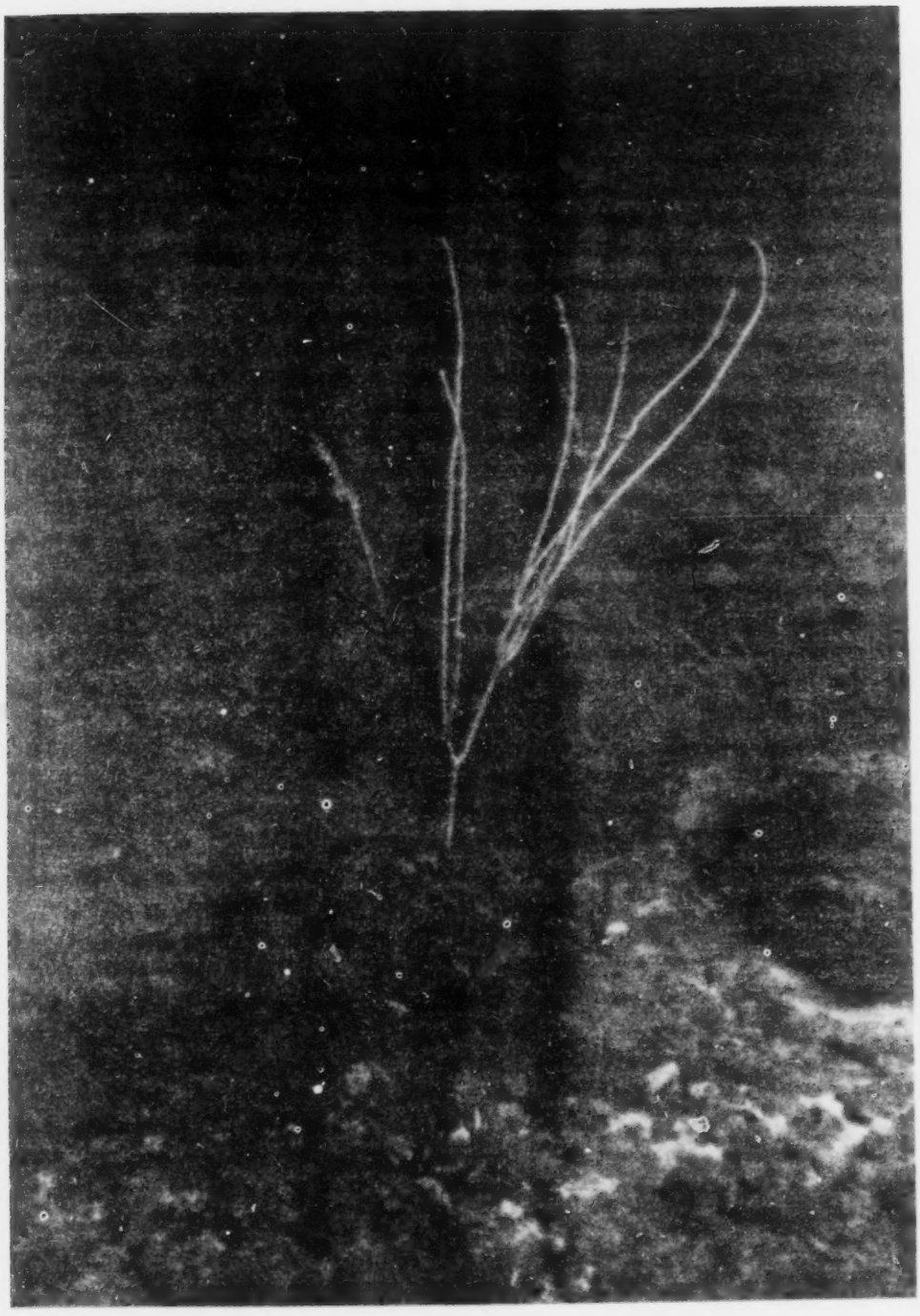
AGORNEA PLATES

In the above slide, most of the agornea plates are all bleaching white. After death, algae begins to grow on the hard surface constructed by the corals.

SLIDE 6

AFFECTED SPONGES

In this slide, the gorgonians, the soft corals, also show bleaching. The large sponges have been affected. Notice the blotchy nature of this one, almost as if they have powder on them.

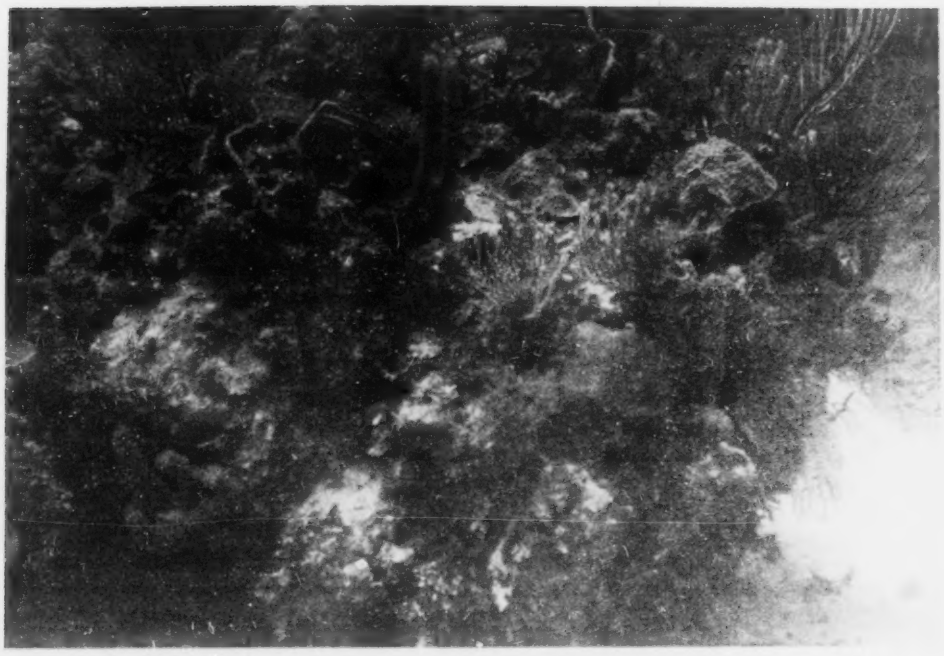


SLIDE 7

BLEACHED GORGONIANS

Again, a slide showing some more of the bleached gorgonians.

Now, we will go and look at slides of the other regions off Lee Stocking.



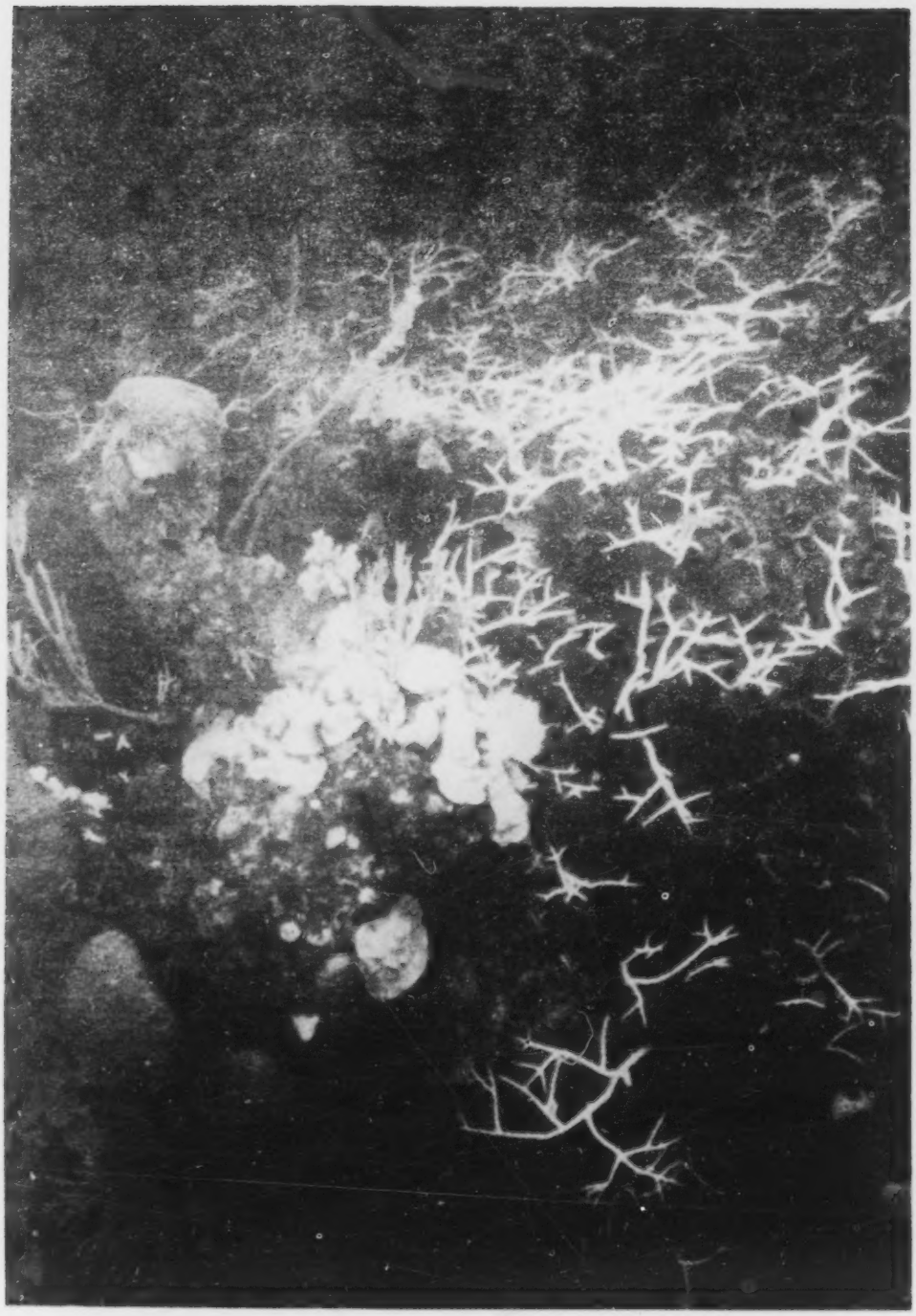
SLIDE 8

NORMAL REEF

This is the way a normal reef looks. This was taken in 1984.

SLIDE 9

Again, 1984.



SLIDE 10

AREA AFTER BLEACHING

This is what the same area looks like after bleaching.

SLIDE 11

AEROPERA CERVICORNIS

These are thickets of aeropera cervicornis, again, all bleached out; upclose. Notice the way the algae are beginning to grow on the dead coral areas.

Now we will look at an area which is one of the areas where we take students because it had some of the most beautiful corals that we had in the area.

SLIDE 12

BLACK BAND DISEASE

This is, again, bleached out. This coral head shows what we call black-band disease. It is something that people have known about for several years and have seen expanding in area but here you have a coral that not only has a black-band disease, but it also has bleaching.

SLIDE 13

PARTIALLY AFFECTED HEAD CORAL

Here is a head coral with one side affected, the other one not.

Fig. 4. Bathymetric chart of the Caribbean Sea and surrounding areas, show he major morphological features.

SLIDE 14

AREAS OF SERIOUS BLEACHING

The slide above shows the Caribbean, the southeast United States, and the Bahamas. We have found bleaching at the Cayman Islands, Jamaica, Hispaniola, Puerto Rico, over here in the Antilles, all through the Bahamas, and in the areas off Florida. The total area affected is about a quarter of the size of the United States, to give you some idea of scale.

So, you see, this bleaching is a big problem area, and it has one thing in common, and that is that the northern Atlantic equitorial current sweeps in across this area; comes up; loops back over in here in the Gulf of Mexico and comes back up through this area off Florida as the Gulf Stream. It has its origin off Africa. That means we may be looking at a global problem. We don't know whether the zooxanthellae are affected or whether it is the corals that are being affected. We really don't know anything about what is happening to cause bleaching, but we do know it is big.

I believe bleaching could be related to a global problem like the Diadema die and the grounding of porpoise. I think we have something here that could be equally as serious as acid rain or the loss of the ozone layer. I think it is a problem that we are going to have to study right away. Because we have to know what we are dealing with, and we have to do it now while it is taking place.

CREATION OF TASK FORCE

I suggested that we form a task force made up of scientists who are currently working in the areas where bleaching is occurring and who have a personal knowledge of the coral and the environmental conditions which are affecting corals.

The main objective of the task force will be to develop a coordinated program to study the bleaching, find out how widespread it is, find out what its cause is, and also to monitor its progress.

I estimate that a task force workshop and finding out what is now known about bleaching will cost about $60,000. Once the program has been established, I think that the task force should prepare a proposal and that there should be a special appropriation made to fund the joint program over a long period of time to see just how extensive bleaching is and what is its cause and effect on coral communities.

I think we should not only look at the Caribbean area, but we should also look in the other oceans, as well. I have talked to Dr. Okamura, who is the scientific adviser to the Prime Minister of Japan, and he has stated that the Japanese people are extremely interested in finding out about the bleaching in the Caribbean. They are interested in working with us on a collaborative program.

I just got this information about Japanese interest yesterday. They are very much concerned. This shows there are other people in foreign countries who will be willing to participate with us.

[The prepared statement of Dr. Robert F. Dill follows:]

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UNIVERSITY OF SOUTH CAROLINA
COLUMBIA, S.C. 29208
DEPARTMENT OF GEOLOGY

PREPARED STATEMENT OF DR. ROBERT F. DILL

My name is Robert F. Dill, I am a marine geologist holding B.S. and M.S. degrees in geology from the University of Southern California and a Ph. D. in Geological Oceanography from the Scripps Institution of Oceanography of the University of California at San Diego. In 1983, I retired after 32 years of Federal Government Service having worked with the U.S. Navy, NOAA, and the U.S. Geological Survey as a marine geologist and oceanographer. However, I still remain active conducting research and teaching courses in carbonate geology, primarily through my association with the University of South Carolina where I have an appointment as a Adjunct Professor in the Geology Department. Most of my research on Lee Stocking has been self-funded with facilities being generously provided by the Caribbean Marine Research Center (CMRC). I also act as a geological advisor for field programs conducted on Lee Stocking Island by various Universities and professional groups.

You might wonder why a geologist is hear today to discuss a subject of regional stress and bleaching of corals, sponges, and other reef organisms and present findings that appear to be at first glance to be primarily concerned with living organisms a scientific field normally considered by most to be the realm of the biologist. I can best explain this by stating that I am marine geologist that has over the past 20 years specialized in carbonate environments. It is in these areas that limestones form and for most of the rocks of this type their origin is from the shells and calcium carbonate structures that organisms build. A carbonate marine geologist therefore must know biology to be able to understand the conditions under which ancient limestones formed. Further, as part of my background I spent 6 years as the Director of the West Indies Laboratory a campus of Fairleigh Dickenson University on ST. Croix in the U.S. Virgin Islands. During this time I had the opportunity to work closely with biologists, two of whom will be making presentations later in this hearing and I honestly feel that much of my work is more of a biological nature than geological.

During this hearing I will also be representing my professional colleges who have done a considerable amount of work on this subject and who by their unique expertise and specialized equipment could be extremely valuable in determining the extent and occurrences at other times of the stress we are observing by the bleaching of the corals of the Caribbean. Specifically, I wish to name Eugene Shinn and Harold Hudson at the Fisher Island Station Carbonate Laboratory of the U.S. Geological Survey, in Miami Beach, Florida, Dr. Bert Williams of the Tropical Marine Disease Laboratory of the

University of Puerto Rico, and Dr. Phillip Dustan in the Department of Biology, University of Charleston in Charleston, South Carolina all of whom have been working with us in preparing the background for these hearings but who because of the constraints of time were not able to make presentations of their work and present their specific recommendations on future actions that need to be taken to better understand what has happened to the corals and sponges of the Caribbean. I wish to make it clear for the record the persons here at the hearings are not the only scientists working on this problem or that we are necessarily the first to recognize this problem. The people before you represent only a small part of the overall group of concerned scientists who are or want to work on the problem. I have over the past two weeks been contacted by many scientists with diverse backgrounds who can make significant contributions to any future studies that might result from these hearings.

My personal involvement in this problem really had its beginnings as far back as 1984, shortly after Robert Wicklund became the Director of the Caribbean Marine Research Center. I began making at least 2 trips per year to Lee Stocking Island to teach college courses in carbonate geology and conduct independent research on the reefs and associated marine environments of the region. During this period of time my associates and I have been able to document by underwater photographs, vidio tapes, and motion pictures the diverse and extremely interesting pristine environments which can be studied in this region of the Exuma Islands of the Bahamas. The region is remote from the pollution usually associated with coastal regions of the United States and the high population areas of the Bahamas and other Islands of the Caribbean. Utilizing the excellent support facilities available at the Caribbean Marine Research Center, we have been able to develop a modern research program that utilizes the natural environment as its laboratory. Much of the results from our research over the past 3 years appears in a Geological Guide Book, which has been published by the University of South Carolina.

In July of this year (1987), I spent 3 weeks on Lee Stocking supervising a graduate student and making reconnaissance dives on the reefs and related environments that surround the island. This search permitted me to visit many of the areas which have a divers and extensive coral population. At that time, I saw no evidence of stress or diseased coral beyond that which we normally find in the area based on the 3 previous years of observations. A review of the photographic coverage we have of the reefs over the same time period confirm these observations. In September I again returned to the island and working with Robert Wicklund and other members of the Caribbean Marine Research Center found that most of the reefs I had visited in July were badly stressed and that most of the large head corals observed previously, lacked their zooxanthella. These are small algal cells which live in the outer layers of the coral polyps and are necessary for the health and growth of corals. Their role in the life cycle of corals will be covered in detail later in the hearings. These plants give corals the brown to green color normally seen in the underwater photographs you will see in the slides I am about to show and in the photographs attached to the copies of my testimony. The affected corals without zooxanthella ~~corals~~ appear bleached and are white to cream colored. The biological reasons for this bleaching and a better description will be covered by the next panel of scientists. After we had made the discovery of bleaching on Lee Stocking Bob Wicklund and I contacted our colleges in other areas of the Caribbean to see if the bleaching had occurred in their areas. We found that the problem was wide spread and observed in Jamaica, The

Dominican Republic, Puerto Rico, The U.S. Virgin Islands, The Lesser Antilles, South Florida including the Keys, The Caymen Islands and possibly the Texas Flower Gardens, in the Gulf of Mexico. This large region which is about a quarter the size of the entire United States, has an oceanographic condition that is in common, it is washed by the waters flowing into the Caribbean from the Atlantic North Equatorial Current that has its origin off Africa. Off the United States its most familiar branch runs along the east coast of the United States and is called the Gulf Stream. The bleaching of corals and sponges if related to this water mass could be a global problem and we could be seeing the beginning of a very serious condition that could rival acid rain and the loss of the ozone layer. One can not help but wonder if the mass mortality of porpoise, the die back of the black spinney urchins and other reef mortalities seen over the past several years are related the rapid bleaching we have observed over such a wide area over the past 4 months!

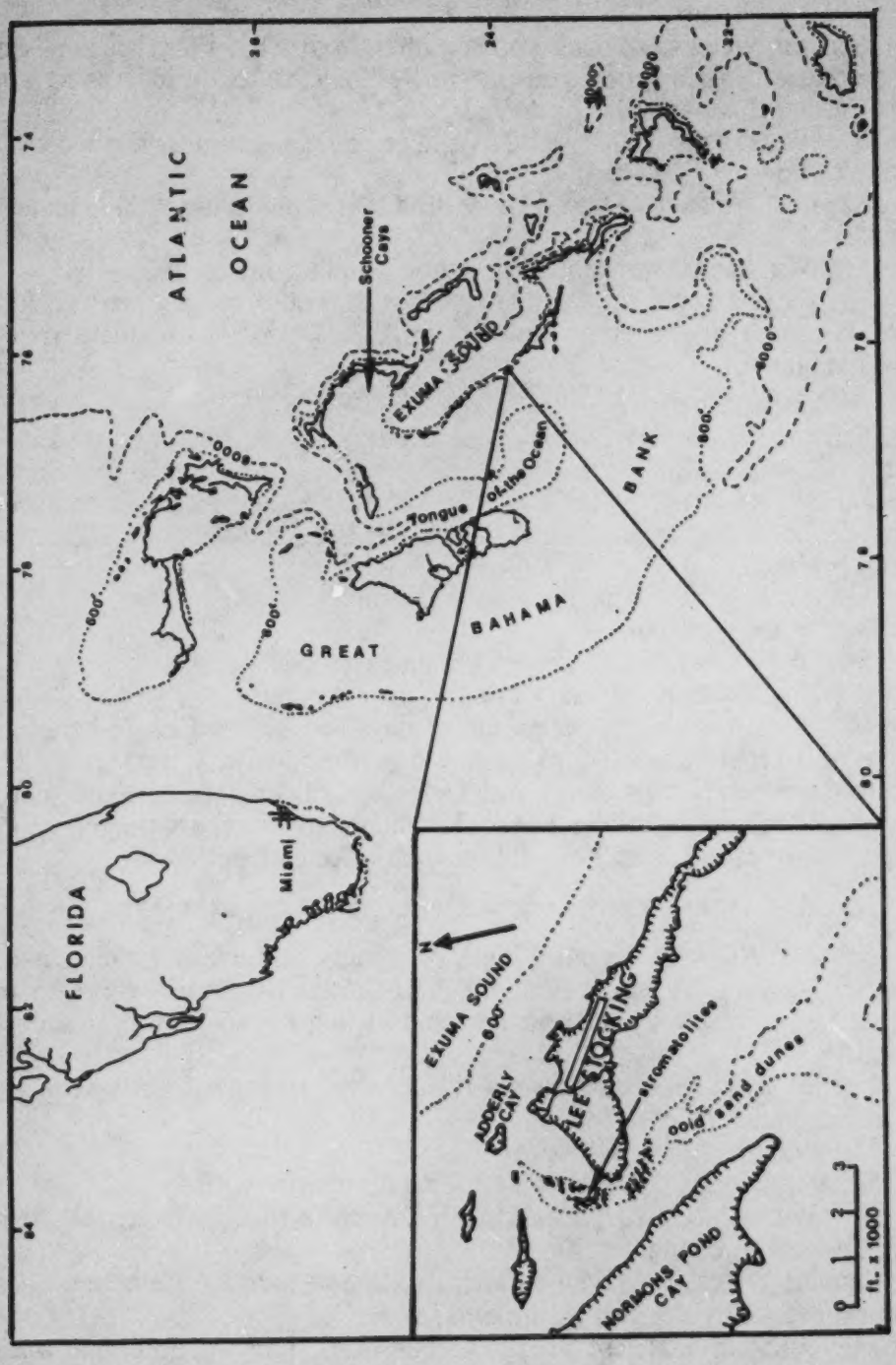
We can not ignore what the bleached corals and sponges are trying to tell us because the problem could eventually affect all of the organisms that depend on coral reefs as nurseries, havens from predators, and in the case of man protection of shorelines and recreation areas. I therefore make the following recommendations;

1. A task Force be formed, made up of scientists who are currently working in areas where bleaching is occurring and who have personal knowledge of the environmental conditions which are affecting the corals. The main objective of the Task Force will be to develop a coordinated program of study to determine the cause of bleaching, how wide spread it is and how to monitor its progress. The Task Force should be funded through a Federal Agency in FY-1988 so that the necessary studies and personnel can be identified as soon as possible. It is estimated that the cost of putting together the preliminary program by a work shop and preparing a research proposal will be $60 K.

2. Once a program is established based on the recommendations and the back ground provided by the Task Force it be funded by a special appropriation. The Task Force should have the proposal completed for submittal by the end of January, 1988.

3. Areas in the Pacific Ocean should be checked to see if bleaching is also occurring at a rapid rate in other oceans.

4. It is strongly recommended that the Caribbean Marine Research Center and its associated Institutions be appointed as the lead laboratory to coordinate the development of the Task Force proposal and choosing its members.


ATLANTIC
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CAUSES OF CORAL BLEACHING UNKNOWN

Senator WEICKER. Thank you. I gather from what both you and Bob say that at this juncture, you just really don't have any idea as to what is causing this particular problem?

Mr. WICKLUND. That's right. We have some suspicions, but we really don't know.

Senator WEICKER. Did we ever find out what caused the Diadema kill?

Mr. WICKLUND. Not that I know of. I don't think so.

Dr. DILL. I can't answer that question. I would suggest we ask Judy or ask some of the other panelists on this. I am not confident that it has an answer.

KILL RATE OF CARIBBEAN CORAL

Senator WEICKER. What has been the rate, as you have observed it, of this particular kill?

Mr. WICKLUND. We first saw it in late September, early October, and it was occurring at that time. Three weeks before that, we didn't see any problem.

Senator WEICKER. This is about a year ago?

Mr. WICKLUND. No.

Senator WEICKER. This September and October?

Dr. DILL. Within the last 4 months, 3 or 4 months.

Mr. WICKLUND. I dove a couple of days ago before I came here, and it is still progressing. It looks worse now than it did 3 weeks ago. The corals are deteriorating very quickly. You will hear from some of the other witnesses that came to the Bahamas and found that some of the species are as much as 90 to 100 percent affected in one area.

RELATIONSHIP BETWEEN DIADEMA AND CORAL

Senator WEICKER. I realize we have others that can comment, and I hope they will. In fact, I hope all those in the panels will listen to my questions amd try to work in responses when it becomes your time to testify.

For a layman, is there any relationship biologically between the Diadema and the coral?

Mr. WICKLUND. Well, just in——

Senator WEICKER. Are they two separate entities entirely?

Mr. WICKLUND. Are you asking if the same thing affected Diadema that is now affecting coral?

Senator WEICKER. Maybe a variant of it, and then let me take a quantum jump: Why not fish in the area?

Mr. WICKLUND. These are good questions, but we don't know the answers to them.

Dr. DILL. You are asking the questions that we need to get together and actually make the program to answer these questions. I think there is one thing that you have to realize. The corals are carnivorous. They eat zooplankton. The zooplankton may be bringing something into this area. They are at the low end of the food chain. This may be just a

beginning. Maybe it already has begun with the porpoise. Maybe that is what is causing their problem. We don't know. That is the frightening thing about it, we just don't know. That is why we have to jump and get something going.

PORPOISE KILL ON EAST COAST

Senator WEICKER. Let's talk just for a minute about the porpoise kill. That took place in an area that is very dense in population. So wouldn't that be a somewhat different set of circumstances than this, as you say? I have been to the Caribbean many times, and it is very isolated in terms of population.

Mr. WICKLUND. Actually, from what I understand, some of the porpoise and dolphin kill was found far off the shores of North Carolina.

Dr. DILL. It is in the deep water, same oceanic water mass.

Mr. WICKLUND. It is not necessarily in a polluted coastal area.

Senator WEICKER. Just to carry that one step further, we just had an enormous fish kill in Long Island Sound this summer. My God, the place was absolutely white with fish. That, I gather, is an oxygen problem when we get into a cul-de-sac such as Long Island Sound.

So you are confident that that would be separate, but you are not confident that the porpoise problem and the one down in the Caribbean are the same?

Mr. WICKLUND. It could be related. If it is a climatic problem it could be global in nature; if it is warm water, and I am not suggesting that it absolutely is, but if it is exceptionally warm water in the Caribbean that caused the problem with corals and that in turn was a result of a climatic perturbation and if a quiet climatic period prevented the waters of Long Island Sound to not causing to mix properly, a depletion of the oxygen, it could all be the same global or climatic event.

So under those terms, that could be a tiein. But, of course, we don't know for sure.

Dr. DILL. As a geologist, we look back in time, of course, and that is one of the things that we find out, what is happening and how we can interpret what changing environments are, and we see extinctions; we see major things happening.

The last 4,000 years on earth has been the most stable period in the last 100,000 years. It is the only time that we have had a stable sea level; our temperatures have been relatively stable; and the conditions that exist now are anomalous, where man came into being.

We may see the beginning of another normal change, and I think this is the thing that we really have to look at on a broad global basis. This may be something that the organisms are trying to tell us, and we have to know more about it. I think it is really serious.

Senator WEICKER. Which is lower in the chain, the Diadema or the coral?

Dr. LANG. No question, the corals.

STATUS OF DIADEMA

Senator WEICKER. The coral is? What has happened—and again, others can answer the question when your turn comes to testify—what has happened to the Diadema? From my own observation, there has been some return of Diadema, at least around the Island of St. Croix.

Dr. LANG. Very much.

Senator WEICKER. I see more of them there. Really, as far as I am concerned, God can do us a favor and get rid of them. But, seriously, I have had to become cautious again. There was about a year there where I walked around with impunity and did whatever I wanted to do. Not any longer.

My question is really twofold. Number one, is the Diadema coming back, and number two, has it been replaced with anything else? We have seen, and I speak strictly as a layman, where on land certain species of animals and certain species of plant life become extinct yet are replaced by others that have adapted to the new environment, whatever it is.

What do you see happening here? Has this happened to coral in the past? Are there species of coral no longer existent, and new species of coral that we see in more recent times?

Mr. WICKLUND. I want to just answer the first part of your question. They are definitely coming back in the Bahamas. We have seen an increase in numbers, but it is very slow; nothing like the way it was before 1983. But they are coming back.

When you lose one animal it can be replaced by another, as far as the Diadema is concerned, its loss was replaced by grazing fish and we don't see a real effect of the loss of Diadema, at least in our area. The fish, in other words, have taken over the job of the Diadema.

But in other places of the Caribbean, which have been fished out, and indeed a lot of the Caribbean has been fished out, there are problems in these areas of abundant corals and it could be because there is no grazing fish or few of them left to take over the grazing job that the Diadema covers.

The Diadema keep the algae down on the reefs so that they don't compete with the corals. So in this case, after we lost the Diadema in at least the Bahamas, this problem would not exist.

FEDERAL AGENCY RESPONSIBILITY FOR INVESTIGATION

Senator WEICKER. Let me just ask one last question. Obviously, we want to do something in a coordinated way here. How is this best approached, in other words? Who is going to do this? NOAA?

Mr. WICKLUND. I think certainly NOAA would be the perfect vehicle for looking and coordinating the problem, particularly since a lot of us here are involved in one NOAA program or another. Of course, a lot of people on the outside could also contribute.

Senator WEICKER. Where did you get your cost estimate? It sounds awfully low.

Dr. DILL. This is for the study that could prepare a proposal that could go in for a bigger study. What we need to do is get the people who have already seen this together, and a lot of us are poor, and we are being funded by the abject poverty foundation that is money normally for food, clothing and shelter and our own housing, and so the thing that we need to do is have a workshop, and that $60,000 would be to have the workshop; allow people to go around and make telephone calls; go out and look at these areas; pull the people together; and then, with this group, I would say we are talking about 15 to 18 people who have been working on this.

These are just rough numbers. Have these people, then, determine what really needs to be done; write a proposal; and then submit it to the proper agency and NOAA could very well be that agency. The U.S. Geological Survey could be it. NSF could be it, and then have appropriations to fund a well-coordinated program that had some thought ahead of time so that we have been a coordinated program bringing in the people that can really do this.

The last thing we want to do is run out everywhere and say, "Let's get all this other information." I think we need to sit back, but hurry, and say, "What do we need to do, and when do we need to do it to find out what is causing it? How widespread is it, and the progress, and what are the implications?"

This would be my recommendation. That is mine; that is not anybody else's.

Senator WEICKER. All right. I thank you. Your statements in their entirety have been placed in the record, and we will proceed with the other witnesses. If there are further questions, they will be submitted to you for response for the record.

Panel 2

TEXAS MEMORIAL MUSEUM

STATEMENT OF JUDITH C. LANG, PH.D., CURATOR OF INVERTEBRATE ZOOLOGY, TEXAS MEMORIAL MUSEUM, UNIVERSITY OF TEXAS, AUSTIN, TX

ECOLOGICAL AND ECONOMIC IMPORTANCE OF CORAL REEFS

Senator WEICKER. Our next witnesses are Dr. Judith Lang, Curator of Invertebrate Zoology, Texas Memorial Museum, University of Texas at Austin; then Walter Jaap, Biological Scientist, Bureau of Marine Research, Florida Department of Natural Resources.

Go ahead.

Dr. LANG. Senator Weicker, thank you for the opportunity of appearing before this subcommittee today. For brevity and because the ecological and economic importance of coral reefs are inextricably intertwined, I shall address both of these topics simultaneously.

Coral reefs are mostly restricted to warm, shallow, clear blue oceanic waters. They are composed largely of calcareous skeletons of reef corals,

animals whose soft tissues contains populations of symbiotic algae called zooxanthellae. The pigment of these algal symbionts give reef corals much of their color and, somehow, their presence allows them to grow with unusual rapidity.

Being a major site of calcium carbonate deposition, coral reefs form an important buffer in the global carbon dioxide cycle. Consolidation of corals and of other calcareous organisms create the framework of a reef. During storms, this framework serves as a breakwater, greatly reducing erosion and attendant losses, both ecological and economic, in tropical lagoons and along shorelines. Throughout the tropics, the skeletons of dead corals are also used commercially for use as a building material or crushed to make gravel or to manufacture cement.

Some of the skeletons of these corals and of other calcareous organisms become fragmented and end up forming the white coral sand which so enhances the recreational and commercial value of many tropical beaches. Coral sands are also mined for use in beach replenishment and for other constructional activities.

Despite their location in a virtual oceanic desert—blue water is very poor in nutrients—coral reefs are among the most productive of all natural ecosystems. The fast growth rates of reef corals apparently are facilitated by close cycling of nutrients between the animal hosts and their symbiotic zooxanthellae.

OTHER LIFE FORMS ON CORAL REEFS

In addition, many kinds of free-living algae inhabit reefs. Some of the non-calcareous algae can grow even faster than reef corals do. Fortunately, on reefs which have not been overfished, the normal feeding activities of herbivorous fishes and sea urchins such as Diadema usually prevent these algae from overgrowing and smothering the corals.

Many other fishes, crustaceans, molluscs also live on reefs, although some make regular excursions into surrounding lagoonal ecosystems in order to feed. Hence, coral reefs are a critical component of many coastal fisheries. Worldwide, average reef fisheries' yields are estimated at nearly 43 tons of biomass per square mile per year. In 1982, the value of just the commercial spiny lobster catch in Monroe County, FL, was approximately $15 million. At present, however, most commercial fisheries in the western tropical Atlantic have been overfished and are highly vulnerable to disruption.

In numbers of contained species, coral reefs are among the world's richest ecosystems. The intricately-formed coral skeletons provide attachment sites for many sedentary organisms and shelter for numerous motile animals. Some of the more visually attractive of these organisms are harvested for the aquarium trade or as decorative objects and jewelry.

Many reef organisms are known to contain unusual and even toxic chemicals. Although only a few medically-important compounds have had their origins here, the medical and commercial potential of this species-rich reservoir is, as yet, relatively untested.

AESTHETIC AND RECREATIONAL VALUE OF REEFS

Without question, however, the greatest economic contribution of tropical beaches and coral reefs is in their aesthetic and recreational value. Tourism, which is largely concentrated in coastal areas, presently accounts for about 40 percent of the gross domestic income of the Caribbean Island nations. In addition, the minimum, non-market use value of the coral reefs in Key Largo State Park in Florida is nearly $3,900 per square meter, which means that a single reef here, Molasses Reef, is worth about $500,000,000.

HIGH VULNERABILITY OF CORAL REEFS

Despite their high productivity and diversity, coral reef ecosystems are easily disturbed. Once perturbed, their rates of recovery can be fairly slow. Unfortunately, reefs are proving to be particularly vulnerable to a variety of perturbations associated with habitat degradation or with development in nearby coastal areas.

For example, many reef corals are killed or show reduced rates of growth when sediment levels are increased, as when land is cleared or when channels are dredged. Increased nutrient levels, commonly associated with sewage outfalls, allow fleshy algae gee to bloom and displace reef coral.

In general, the combined effects of such stresses are probably most severe when reef corals are close to their physiological tolerance limits for some environmental factor.

Many coral reefs and associated commercial fisheries in the western Atlantic have deteriorated within the last several decades. Indeed, the oldest marine park in the United States, John Pennecamp, is now ranked as one of the world's ten most threatened protected areas.

Limited experience indicates that reefs can recover once artificial stresses are reduced but, to date, there have been few such improvements in this geographic area.

In summary, the ecological and economic value of coral reefs is considerable but can only be realized when reef ecosystems are managed as fragile but renewable resources and when they are exposed to a minimum of artificial stresses.

Thank you.

[The prepared statement of Dr. Judith C. Lang follows:]

Prepared Statement of Judith C. Lang

Texas Memorial Museum, University of Texas, Austin, TX 78705 and
Department of Zoology, University of Texas, Austin, TX 78712

Ecological Importance of Coral Reefs

Reef corals (scleractinians and Millepora) are sessile, marine animals which secrete a skeleton of calcium carbonate as they grow. Their soft tissues contain populations of symbiotic zooxanthellae (Symbiodinium--a photosynthetic alga). One result of this mutually-beneficial association is that the extension rates of the zooxanthellate reef corals are relatively rapid, usually 1-20 cm/year. Large coral colonies may contain many thousands of individual polyps, and be hundreds or even thousands of years old.

Compaction and consolidation of the skeletons of reef corals and of other calcareous reef inhabitants create the frameworks of coral reefs--massive structures with high accumulation rates (up to 12 meters/1000 years) which significantly alter the relief of surrounding sea floors. Globally, coral reefs cover at least 600,00 square km, or about 0.1% of the planet's surface. Most reefs are located in clear, shallow, oceanic waters of the tropics and subtropics. As a major site of calcium carbonate deposition, they form an important buffer in the global CO_2 cycle.

Broken-down skeletal fragments of carbonate-producing reef organisms are major constituents of "coral sands". These fine-grained particles (really a mixture of silts, sands and gravels) are transported by waves and currents away from reefs, providing sediment for the lagoons, beaches and islands which develop in their lee. By dissipating the energy of waves and currents, reefs also serve as breakwaters, thereby reducing erosion in such lagoonal and nearshore ecosystems as seagrasses, mangroves and sandy beaches.

Coral reefs are among the most productive of natural

ecosystems. Despite their location in blue waters which are poor in nutrients, estimates of gross primary production range between about 300 and 5,000 gm carbon/square meter/year. Important primary producers on reefs are the zooxanthellate corals, other algal-aminal and algal-protozoan symbioses, free-living filamentous, fleshy and calcareous algae and phytoplankton. High productivity is presumably maintained in part by close cycling of nutrients between reef corals and their zooxanthellae, and among other producers and consumers. The contributions of free-living, photosynthetic cyanobacteria (blue-green algae) which are capable of fixing dissolved gaseous nitrogen may be especially important in some reef habitats.

Trophic relationships are particularly complicated on reefs, as illustrated by the reef corals themselves. Organic photosynthates which they receive from zooxanthellae apparently facilitate the production of mucus and the growth of their soft and skeletal tisses. In addition, reef corals actively feed on free-living zooplankton and, perhaps, other exogenous foods, at least in part to obtain essential mineral nutrients for their algal symbionts. Similar nutritional relationships exist between many other reef animals and their zooxanthellar symbionts, regardless of whether or not the former deposit calcareous skeletons.

In turn, the soft tissues of reef corals are eaten by certain specialized predators. Some fishes and invertebrate animals consume mucus (produced by corals to clear sediment and capture small plankton) which they have gentled sucked or scratched from the surfaces of live corals. In addition, strands of mucus which have been released by corals are eaten by benthic scavengers or, as currents waft them away, are snapped up by pelagic zooplankton and fishes.

The movements of motile animals form important trophic links between coral reefs and other ecosystems. Demersal zooplankton, which hide in crevices of the reef by day and emerge in the

evening to feed in the water column above, are themselves preyed upon by reef corals and other sedentary invertebrates as they pass to and fro. By foraging in nearby seagrass beds at night, diverse fishes, sea urchins and other invertebrates import significant quantities of nutrients into reefs from surrounding ecosystems. The wastes which they subsequently eliminate contain nutrients which measurably increase growth rates of the corals under which they shelter by day.

Coral reefs are among the richest ecosystems in the world in terms of the number of species of living organisms which they contain. The skeletons of reef corals create topographically complex structures, thereby providing attachment sites for numerous sedentary organisms (including other corals) and shelter for motile fauna. Among the sessile flora and fauna are many species which compete with each other for space and, presumably, for access to nutritional resources. Complicated variations in competitive outcomes, both within and among species, apparently enhance the coexistence of these competitors, even on reefs which are structurally dominated by a few species of large, "canopy-forming' reef corals.

Other species are borers which excavate cavities in coral skeletons to provide space for their own tissues. Certain fish and sea urchin grazers scrape off surficial skeketal layers as they feed. Collectively these bioeroders weaken the surface frameworks of reefs, and create many of the fine-grained particles which end up in nearby lagoons and on sandy beaches and islands.

Crustose coralline algae and foraminifera, however, bind coral skeletons to the substratum, hence contributing to the formation of reef frameworks. Moreover, in return for food, small crustacean symbionts deliberately protect certain species of host corals from predatory starfish. Some large scavengers inadvertently may prevent rapidly-extending branching corals from

expanding over the more slowly-growing, mound-shaped species at whose bases they find shelter.

Complicated indirect relationships also exist between corals and other reef organisms. For example, herbivorous fishes and invertebrates crop the fleshy, benthic algae whose abilities to grow rapidly in shallow reef habitats are often so great that, uncontrolled, they easily would overgrow and smother many reef corals.

The Economic Importance of Coral Reefs

Economically, coral reefs represent one of the most important marine resources of the tropics. Reefs dissipate waves, minimizing the impact of storms on commercially-important lagoonal ecosystems and on port facilities, houses and other coastal installations. By serving as sources of food, shelter or as nursery grounds for fishes, crustaceans, molluscs and echinoderms, coral reefs also form the basis of many coastal fisheries. Traditionally these resources provided much of the consumed protein in the diet of tropical islanders. Even to-day, about 180 species of reef fishes are harvested for human consumption in Puerto Rico. The value of all reef-related, commercially-edible organisms in Monroe County, Florida, was estimated at approximately $19,000,000 in 1982 (spiny lobsters accounted for $15,000,000 of this total). Worldwide, average yields of reef fisheries are estimated at nearly 43 tons of biomass/square mile/year in depths of less than 100 feet. Although aquaculture of reef organsims has been little developed to date, the Caribbean King Crab is a promising candidate for such activities.

Reefs contain numerous non-edible resources of considerable commercial importance. Throughout the tropics, the skeletons of reef animals are major sources of sand and gravel. Both modern and fossil corals are quarried for limestone to use for construction and in the manufacture of cement. Some of the more

visually attractive live algae, fishes and invertebrates fetch high prices in the aquarium trade. In addition, the skeletons of reef corals, precious corals, soft corals, molluscs and other dead reef organisms are sold as decorative objects or for jewelry by entrepreneurs around the world.

Medically-important chemicals which have been extracted from reef organisms include prostaglandins, an anticancer agent, and an ultraviolet blocker recently synthesized for use as a sun cream. Given the high species diversity of these communities, that many sedentary reef organisms contain unusual chemical compounds, and the known toxicity of numerous reef inhabitants, reefs represent a vast and, as-yet largely untapped, reservoir of chemicals which potentially are of both medical and commercial value.

In many tropical and subtropical areas, vital parts of the tourist industry are concentrated in coastal areas. Here, reef-derived sandy beaches make an important contribution to the recreational value of the coastlines. The livelihood of operators of glass-bottom and sports-fishing boats, snorkeling and SCUBA-diving facilities, and numerous coastal merchants, are further dependent upon the clear blue waters and the intrinsic beauty for which coral reefs are renowned. Tourism presently accounts for about 40% of the gross domestic income of Caribbean Island nations. The minimum, non-market use value of the coral reefs in Key Largo State Park has been estimated at nearly $3,900/square meter. By this criterion, Mollasses Reef alone is worth $500,000,000.

Vulnerability of Reef Ecosystems

Their high productivity and diversity notwithstanding, coral reef ecosystems are easily perturbed by external disturbances, and their rates of recovery can be fairly slow. For example, most reef corals live near their upper thermal limits and those growing at high latitudes (e.g., Florida, northern Bahamas, Bermuda) may also be killed by cold temperatures in winter.

Deviations of salinity or light from optimal values appear to further narrow the range of tolerable temperatures in reef corals. On many reefs, extreme levels of mechanical damage are associated with the periodic passage of hurricanes. In addition, reefs can be devastated by population explosions of predators (especially the Crown-of-Thorns starfish in the Indo-Pacific), or diseases, and by altered predator-prey ratios following disturbances that disproportionately affect reef corals. Natural disturbances do, however, open patches on coral reefs which, if colonized by surviving reef organisms and new recruits. contribute to the high species diversity of these communities.

Unfortunately, reefs are particularly susceptible to pertubations associated with habitat degradation or development in nearby coastal areas. For example, excessive levels of sediment, nutrients and other pollutants decrease the growth rates of established corals, and probably limit their sexual reproductive activities and the ability of juveniles to settle in open patches. Large increases in bioeroding organisms (which potentially could shift the carbonate balances of reefs) have been noted under conditions of sewage stress. In general, eutrophication allows fleshy algae to bloom, grow above, and eventually smother reef corals and other sedentary animals. Although reefs which are chronically perturbed by high levels of artificial stresses may not recover, limited experience to date suggests that reef corals and their associated populations can return if artificial stresses are reduced.

In many areas of the western Atlantic, reef corals are routinely stressed by sediment, industrial or agricultural chemicals, sewage, and eutrophication. Not surprisingly, many of its coral reefs and associated commercial fisheries have deteriorated within the last several decades. The John Pennecamp Coral Reef State Park (the oldest marine park in the U.S) is ranked as one of the world's ten most threatened protected areas. On many central Caribbean reefs, where stocks of herbivores have

been depleted by the combined effects of chronic overfishing and disease, unchecked algal growth presently is occurring at the expense of reef corals.

Conservation Measures

In 1980, coral reefs were identified as one of the world's "essential ecological processes and life-support systems" by the International Union for the Conservation of Nature. Although reefs are still poorly represented among the world's protected areas, worldwide there are, at present, in excess of 200 reserves which offer at least theoretical protection for the reef communities contained within their boundaries. Given the importance of the physical and nutritional linkages which exist among coastal ecosystems, to be effective protection should also be extended to any adjacent lagoons and coastlines and, if possible, any watersheds. Properly managed, such reserves can help to sustain renewable marine resources and provide educational and recreational facilities to the general public. In addition, they are suitable sites for the basic research efforts and long-term monitoring studies which are essential for delimiting the capacity of reef ecosystems either to resist or recover from natural and artificial pertubations.

Bleaching

It has long been recognized that reef corals which are under stress are likely to loose their symbiotic zooxanthellae. When this algal loss is sufficiently great that the underlying coral skeletons are visible below their cover of soft tissues, corals are commonly said to have "bleached". Natural sources of external stress include temperature extremes, subaerial exposure, reduced salinity, increased sedimentation and altered levels of illumination. Bleaching is also observed when reef corals artifically are perturbed by starvation, exposure to certain particulates, oil and to fish collecting chemicals. In general,

synergistic effects among several factors are likely to occur when corals bleach in the field.

Although the underlying biochemical and physiological mechanisms are unclear, the cytoplasm of the affected corals may show reduced lipid levels, degenerate zooxanthellae, abnormal mitochondria, mucoid polysaccharide materials and varying degrees of tissue atrophy and necrosis. Apparently depending on the severity of the stress(es), affected corals gradually either recover a "normal" complement of zooxanthellae or die.

Previously-recorded bleaching episodes in the western Atlantic have been attributed primarily to the effects of high water temperatures, to lowered salinities and, possibly, to increased levels of suspended sediment. Prior to 1987, the only bleaching event which is known to have extended over a fairly wide geographic area (a few sites in Colombia, Panama, Costa Rica, San Andres, Florida and the Bahamas) occurred in 1983 and was possibly correlated with the unusually large, 1982-1983 El Nino Southern Oscillation. Mortality rates appear to have been low at most of these locations. During the same year, however, extensive bleaching and subsequent death of reef corals was widespread across the Pacific and even in the western Indian Ocean.

Present Bleaching Event

A brief summary of my personal observations of the present bleaching phenomenon in Colombia and the Bahamas is followed by a preliminary assessment of this event.

Colombia:

Bleaching of some corals was first observed in mid July at the Islas del Rosario. At this time, water temperatures were about 30°C at 0-3 meters depth and, on at least one day, the water was turbid (indicates the presence of sediment and possibly of exogenous nutrients or other pollutants, its salinity could also have been lowered). By mid-August, loss of zooxanthellae was noted in 14 species of scleractinian reef corals, in

Millepora and in several species of soft-bodied cnidarians. Zooxanthellate sponges were not affected. Overall, the patterns and extent of bleaching were highly variable. both among species and among locations (Tables 1-3), but were confined to shallow (6 meters) habitats. At that time the event was judged to be less severe than the bleaching episode of 1983.

I have since heard that in early August some reef corals were also observed to have bleached at the Islas de San Bernardo.

Bahamas:

Slightly higher than average water temperatures may have occurred in the late summer-early autumn at Lee Stocking Island. Winds may have been more from the south, southwest and west than usual. Bleaching, which was first noted at the end of September, extends to depths of at least ~~60~~ 55 meters. By early October, about 18 species of scleractinians, Millepora. many gorgonians, several other groups of soft-bodied cnidarians, and possibly some sponges had been affected to some degree. In several species, up to 96-98% of the specimens examined were either pale (i.e., containing few zooxanthellae or reduced amounts of accessory photosynthetic pigments), partly bleached (some soft tissues are white) or completely bleached. Patterns and extent of bleaching varied with species and habitat and, in some groups, (e.g., Millepora, gorgonians) increased with depth (Figs. in prep.). At one location one/third (22/67) of the staghorn corals seen had died within the previous week or two, but the reason for their demise is not known. Shallow populations of the related elkhorn coral, however, were relatively unaffected at this time.

Provisional Assessment:

Overall, the near-simultaneous appearance of bleaching in Colombia and Florida in mid-July, and its current widespread distribution (Colombia to ?Bermuda and Virgin Islands to Florida or Cozumel) by late September suggests that some large-scale physical factor(s) is involved. Presumably any pathogens or

pollutants as might be released at a point source could not have dispersed over such a wide geographic area within such a short time frame. Until we know what percentage of the corals which have bleached ultimately will recover, it is not possible to evaluate the ecological or economic severity of this phenomenon.

Should a region-wide, natural physical explanation prove to be the proximate cause of this event, its appearance in such continental shelf areas as Florida and Colombia several weeks to months before the insular locations still needs to be explained. The regional stress(es) could have been experienced first or most acutely here; alternatively, chronic exposures of reef corals to artificial stresses (excessive nutrients, sediment, etc.) could heighten their sensitivities to additional pertubations. Distinguishing between these alternate possibilities would appear to be an important goal, as the answer would, in turn, clarify what intervention, if any, is appropriate from a reef management perspective.

Recommendations

Recommendations 1 to 5 are intended to provide data on the extent and duration of the present bleaching. If available, this information could be compared directly with that gathered in the eastern Pacific since 1983. An important goal is to ascertain whether or not human activities have contributed to its early appearance in Florida and Colombia. Short-term emergency appropriations should be solicited to allow these studies to begin immediately, before the conditions of the affected corals change. (Only rarely after corals have died is it possible to determine the reasons for their demise.)

Recommendations 6 to 11 are for longer-term ecological and physiological studies aimed at determining the cause(s) and consequences of these kinds of events, and at providing environmental data which are essential to document any future natural disturbances. Emergency funds could be used to initiate

these researches, but funds for their continuation should then be solicited from regular granting agencies.

Our ability to understand the potential impact of pertubations like the present bleaching event in reef ecosystems will be greatly enhanced if recommendations 2-10 are replicated at least in one relatively-polluted and in one comparatively-unpolluted reef area.

1. Try to establish a reliable chronologly for the present event, with particular attention to relative timing, wind speed and direction, ambient temperature, salinity, cloud cover and suspended sediment load wherever such information is available. Comparative information on the species which are and (just as important) are not affected, and the habitats in which they occur, would allow certain limits to be placed on the factor(s) which may have initiated this phenomenon.
(In progress at the University of Puerto Rico).

2. In areas for which massive bleaching has occurred in the shallower reef habitats and is visible in plan view, use aerial reconnaisance flights or satellites to obtain false color IR and other photographic information. Digitization of these data would provide large-scale quantification of the effects of bleaching on reef communities.

3. Try to determine if there are any unusual histological features or any microbial infestations present in the soft tissues of the bleached corals relative to controls.
(In progress in Florida at least.)

4. Measure lipid levels (an important measure of nutritional state) in bleached and unbleached corals.

5. Particularly if chronological data suggest that the corals in continental areas such as Florida and Colombia might be chronically stressed, analyze tissue samples and ambient sea water for terrigenous sediment, heavy metals, pesticide and

herbicide residues, etc., and for elevated levels of fulvic acid (an indicator of increased runoff from land).

6. Establish and maintain automated weather stations adjacent to sites for which a good ecological data base of its reef communities either exists at present or will be forthcoming in the near future.

7. Monitor marked, bleached corals and controls at regular intervals until the former either recover or die from the effects of this pertubation.

8. Sample bleached and unbleached specimens of at least several species to determine the effects of this stress upon their sexual reproductive activities.

9. Several years from now, core some surviving massive corals (both unbleached and ones which recover from the bleaching) and use established X-radiographic methods to determine any effects of bleaching on annual rates of skeletal growth.

10. Quantitatively document any changes in the ecological structure of affected reef communities with standardized, time-series transect measurements or photography.

11. Experimentally establish thermal limits for reef corals collected from different habitats as a function of illumination, salinity and water motion. The classical tolerance studies of Mayer (1914, 1918) and of Vaughan (1911) were excellent for their time, but limited to corals collected in very shallow water. They are not an appropriate data base to-day. Subsequent studies of western Atlantic reef corals are of limited scope.

If the chronology of the present bleaching suggests that artificially stressed reef corals are particularly sensitive to the effects of the present pertubation(s), these experiments should be expanded to consider the effects of suspended sediment load, increased nutrient supply and diverse industrial and

agricultural pollutants. Particular attention should be given to synergistic effects which are perhaps of greatest importance near a reef coral's physiological limits of tolerance for any given physical factor.

Table 1

Bleaching Conditions on the Southern Side of Isla Tesoro, Colombia, at Depths of 0-5 m, on August 15, 1987.

Species	Condition: All Bleached	Partly Bleached	Pale	Fine
Scleractinians:				
Acropora palmata		x	x	
A. cervicornis				x
Agaricia agaricites	x	x		xx
A. tenuifolia	x		x	xxx
Siderastrea siderea		x		xxx
Porites astreoides	x	x		xxx
P. porites	x		xxxx	
Favia fragum	x	x		xx
Diploria labyrinthiformis	x	xx		xxx
D. strigosa		xx		xx
Montastraea annularis		xx	x	xxxx
Meandrina meandrites		x		x
Other Cnidarians:				
Millepora	x	x		xxx
Erythropodium caribaeorum	x	x		xx

Table 2

Bleaching Conditions on the Southern Side of Isla Rosario, Colombia, at Depths of 0-5 m, on August 16, 1987.

Species	Condition: All Bleached	Partly Bleached	Pale	Fine
Scleractinians:				
Acropora palmata		xx		
A. cervicornis				x
Agaricia agaricites		x		x
A. tenuifolia	xxx	xxxxx		
Porites astreoides		xx		xx
P. porites		x		x
Favia fragum		xx		xx
Diploria clivosa		x		x
D. labyrinthiformis		x		x
D. strigosa		x		x
Colpophyllia natans		x		x
Montastraea annularis		xxx	xx	xxxx
Other Cnidarians:				
Millepora		xxx		x
Erythropodium caribaeorum	xx	xx		x
Palythoa		xx		

Table 3

Bleaching Conditions on the Eastern Side of the Islas Pajarales complex, Colombia, at Depths of 0-6m, on August 16, 1987.

Species	Condition: All Bleached	Partly Bleached	Pale	Fine
Scleractinians:				
A. cervicornis		x		xx
Agaricia agaricites	xx			
A. tenuifolia	x	xxxx		xxxx
Porites astreoides		xxx		xx
P. porites	xx	xxxx	xx	x
Favia fragum	xx			
D. labyrinthiformis				x
D. strigosa		x	x	
Montastraea annularis		xx		xxxx
Other Cnidarians:				
Millepora		xx		xx
Erythropodium caribaeorum		x		xx
Stoichactis helianthus			x	
Palythoa		xx		x
Zoanthus				x

FLORIDA DEPARTMENT OF NATURAL RESOURCES

BUREAU OF MARINE RESEARCH

STATEMENT OF WALTER C. JAAP, BIOLOGICAL SCIENTIST III, FLORIDA DEPARTMENT OF NATURAL RESOURCES, BUREAU OF MARINE RESEARCH

REASONS FOR MASSIVE CORAL BLEACHING

Senator WEICKER. Thank you, go right ahead.

Mr. JAAP. Senator Weicker, I would also like to thank you on behalf of the State of Florida for this opportunity to present this information. I would like to also give credit to Billy Causey, who is the manager of the Looe Key National Marine Sanctuary, and John Halas, the manager of Key Largo National Marine Sanctuary, as much of the things that I will discuss today came about as a result of their observations.

Massive coral bleaching is an unusual event. It is usually triggered by a major change in some physical or chemical factor that stresses the reef. Coral bleaching has been caused by drastic alterations in salinity, temperature, both heat and cold, light and food deprivation, siltation and when extreme low tides expose reef corals above the surface.

The 1983 El Niño Southern oscillation [ENSO] event was a major cause of coral bleaching throughout the tropical Pacific, and others have already mentioned this: major coral mortality occurred with the 1983 ENSO event.

Bleaching in 1987 has already been reported as having occurred from Bermuda, Bahamas, Southeast Florida, the Florida Keys, the Greater Antilles Island groups; Puerto Rico; St. John, U.S. Virgin Islands and St. Croix, U.S. Virgin Islands; Jamaica; the Cayman Islands; Cartagena, Colombia; Cozumel, Mexico; and the Flower Garden Banks, off the coast of Texas.

Reefs in Caribbean Panama, to our knowledge, were not affected. We are not certain about other areas such as the Bay Islands of Honduras, Aruba, Venezuela, Haiti, Cuba and Trinidad.

The bleached animals include anemones, sponges, stony corals, soft corals, fire corals and zooanthids. The bleaching was observed as deep as 180 to 240 feet in some areas. The earliest reports that we have were in June, and the latest occurred in October.

My written testimony does not indicate the actual date that the bleaching started, but it is an indication of the geographic distribution. As early as July 12, the Florida Keys corals began discoloring. The epicenter of that event was Looe Key National Marine Sanctuary.

Billy Causey, the manager at Looe Key, reported that corals in shallow water were first to discolor, and then over time, the discoloring moved deeper and the discoloring intensified. The animals turned bone white. Fire coral and golden sea mat were heavily impacted. Some elkhorn coral actually died, but we don't know if this is coincidental. A disease may have killed it.

The bleaching expanded by August-September to Hollywood and Palm Beach, FL, in the north and to Key West to the southwest of Looe Key. It probably extends to the Dry Tortugas.

The bleaching includes corals, fire corals, soft corals and sea mats, and bleaching was observed to depths of 80 feet. In some respects, this bleaching appears to fit the hyperthermia model of heat stress. However, in other respects, it does not fit. The bleaching to 180 to 240 feet and bleaching as early as June and July are very abnormal for this region. The widespread distribution of this event is also unusual, and a wider spectra of animals were affected.

An interesting observation was made by Steve Smith, who is a biologist with the Department of Natural Resources in the Cayman Islands. He reported that during a night dive, coral polyps were found to be extended, however, they were not able to feed. The zooplankton was moving about the tentacles, but the corals were unable to catch them.

SLIDE PRESENTATION

At this time, I would like to show you some slides that were taken this year as well as in 1983 that provide some idea of the events.

PLATE 1.—Caribbean Sea. Reef bleaching in 1987 began in June and continued through October. It extended from Bermuda to Curacao, including many of the lesser and greater Antilles, Bahamas, Florida, Cozumel, San Andres, and the Flower Garden Banks off Texas.

EXTENT OF BLEACHING

In the Caribbean Sea, you have already heard about the distribution. We have added just a few places. In the Panama area, of course, no bleaching records; Cozumel, Mexico is the first place, guess you would say, in the western gulf that has bleaching. Then it goes up to the Flower Garden Banks and the Florida Keys.

PLATE 2.—A stony coral (Scleractinia) polyp. The brown collar comes from the microscopic algae (zooxanthellas) that live symbiotically within the coral tissues.

CORAL POLYP

This is a typical coral polyp. You will notice the deep brown color. The zooxanthellae provide most of that color. It is a zooplankton feeder as well as a primary producer. The plant-animal complex is about 40 percent plant material, 60 percent animal.

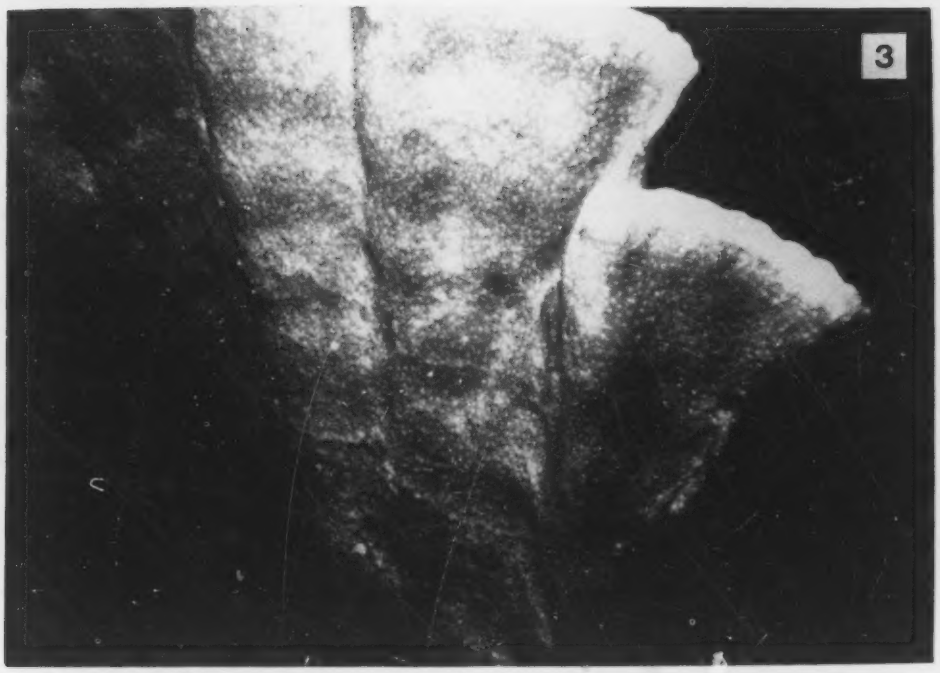

PLATE 3.—The bladed fire coral, *Millepora complanata*. This is its normal color; the white fringe at the tip is new growth.

FIRE CORAL

Typical color of the fire coral when it is not bleached.

PLATE 4.—Sand Key Reef near Key West. Aerial view of the spur and groove formation; note the intense white color.

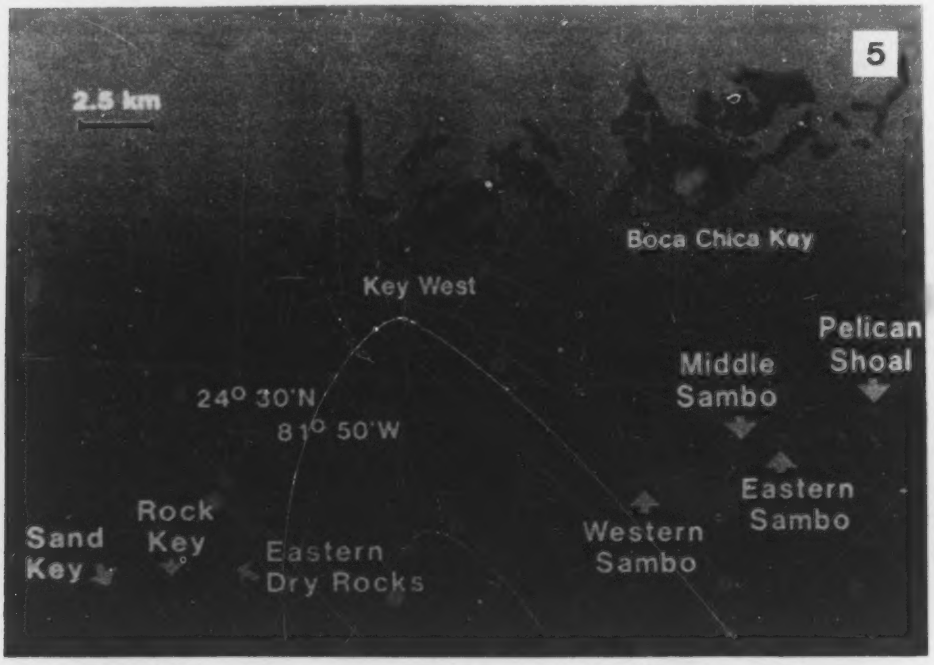

PLATE 5.—Map of reefs near Key West, Florida.

SPUR AND GROOVE TRACK FORMATION

We can see from the aerial photo Sand Key off of Key West, and this is the typical spur and groove track formation that you find in shallow water in any of the Florida Key reefs.

PLATE 6.—Close-up view of Sand Key Reef; spur formations with bleached coral (white features).

AREAS OF BLEACHING

If you look close up, you can see the intense white of the bleached coral. This particular event in 1983 was only around Key West, but this year, it went as far north as Palm Beach and down to the Tortugas area.

In 1983, the event occurred from Pelican Shoal to Sand Key Reef, which is a much smaller area, it didn't have very wide distribution. There was some discoloring further along up the Key chain, but it wasn't as dramatic or as intensive as that observed off Key West.

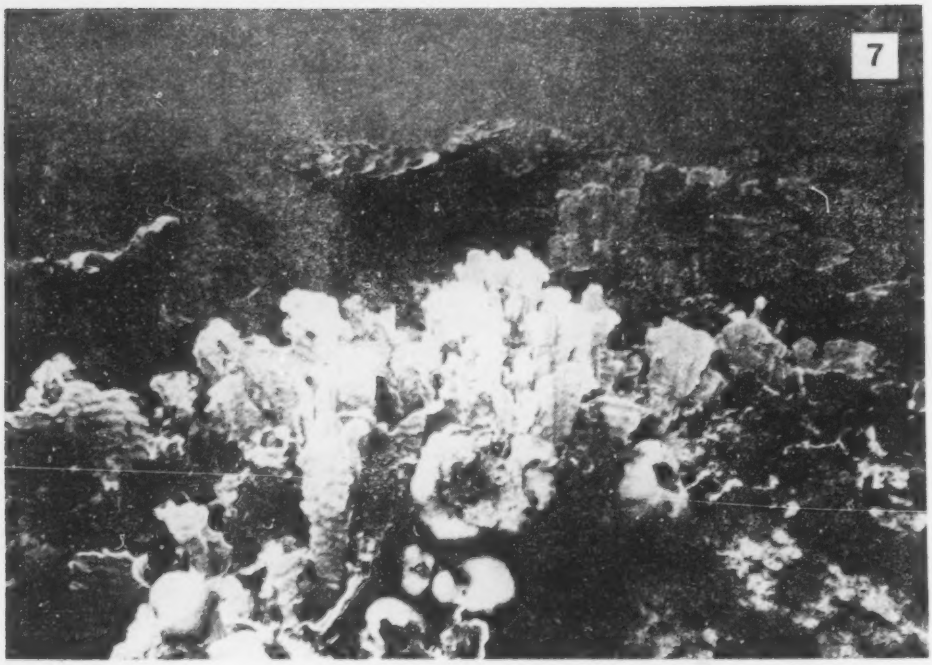

PLATE 7.—Underwater view of Sand Key Reef. White corals in foreground are bladed firecoral (*M. complanata*). The elkhorn coral (*Acropora palmata*) in the background is not discolored.

FIRE CORAL

You can see typically what it looks like in the shallow water. This is mostly the fire coral, *Millepora complanata.* These corals, although they are bleached white as you see them here are still alive; if you rub your wrist up against the surface, it still has that distinctive sensation of burning that you obtain with this species.

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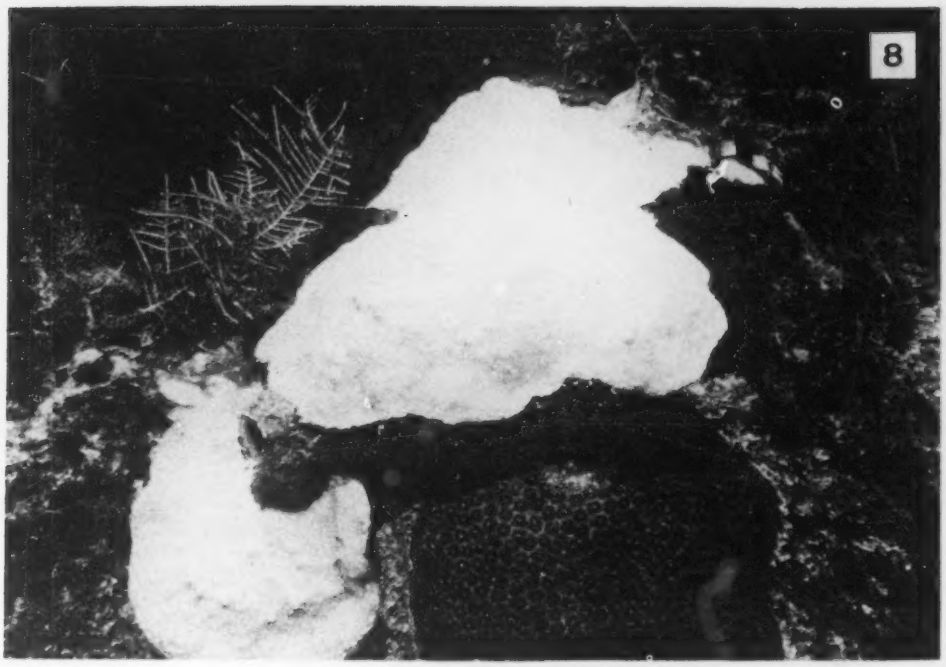


PLATE 8.—French Reef off Key Largo, 60–80 ft, October 7, 1987. *Montastraea annularis* (star coral) bleached, while its close relative (*Montastraea cavernosa*) retained its normal color.

STAR CORAL

A photo taken this year off of French Reef and probably around 65 to 80 feet in depth, this is the star coral, *Montastraea annularus* on the top. You will notice the *Montastraea cavernosa,* its close relative, underneath, was untouched in this particular case.

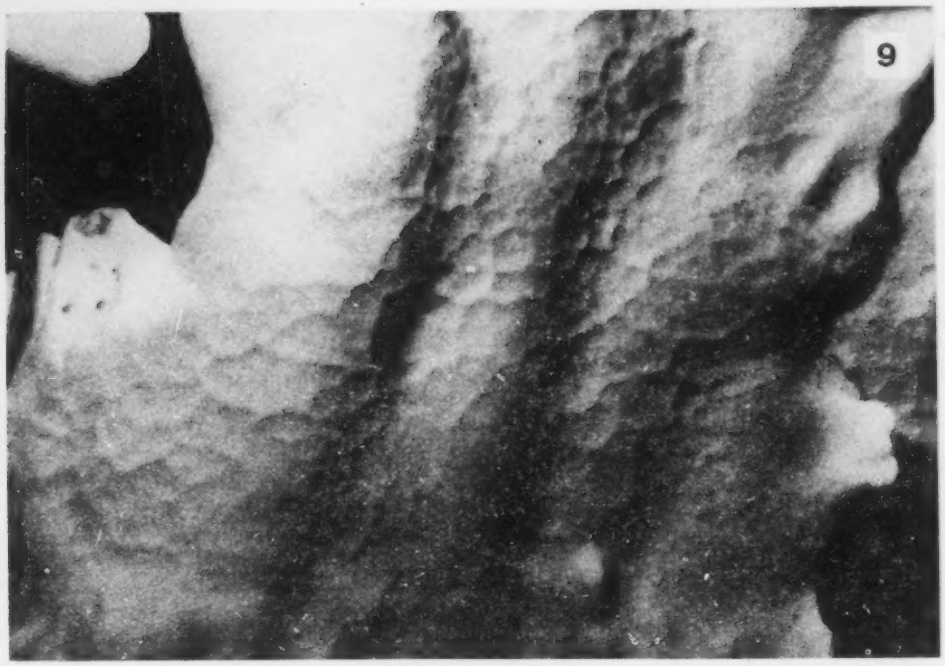


PLATE 9.—Close-up photograph of a bladed firecoral (*M. complanata*) that is totally bleached. Photo taken October 1983, Sand Key Reef.

EXTENT OF DAMAGE FROM BLEACHING

Here is a close-up of what that fire coral looks like when it is totally bleached. There might be as many as 4 million tiny algal cells, zooxanthellae, within a square inch surface area. They are almost all removed from the tissue by the bleaching.

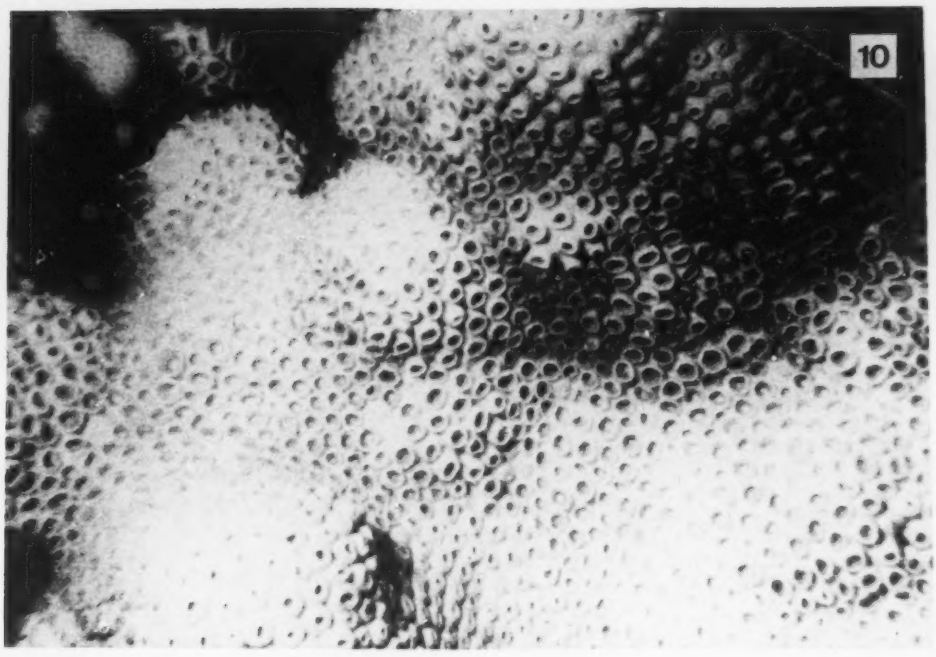


PLATE 10.—A non-coral zooanthid (anemone-like animal) that is discolored. Photo taken at Sand Key Reef, October 1983.

GOLDEN SEA MAT

Here is another example of an organism. The Golden sea mat—normally it has an intensive gold color—here is totally bleached out.

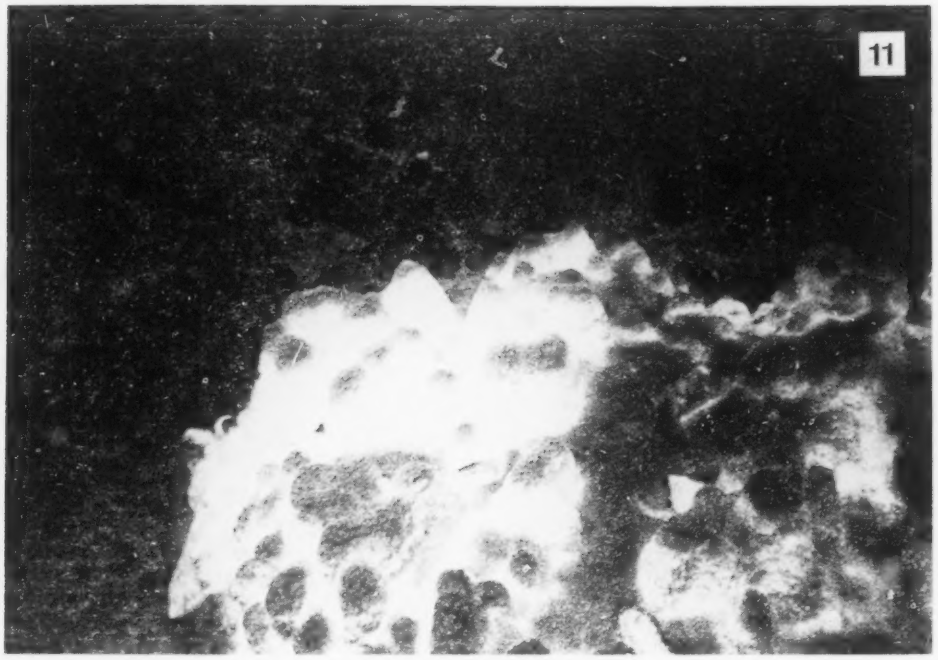


PLATE 11.—Star coral (*M. annularis*) with upper surfaces retaining color, and lower surface areas bleached.

STAR CORAL

One of the star corals. This is typical with the star coral that has a complex surface of little pillars with small micro valleys. The micro valleys tended to bleach out and the surface areas on top still retained some color or remained almost normal. We theorize there is a sinking of dense saline and hot water and that may lay in the lower areas for a longer period of time, that is the cause for the pattern of zebra discoloration.

Some of the corals display this sort of zebra pattern with splotches of normal color alternating with areas that are totally discolored.

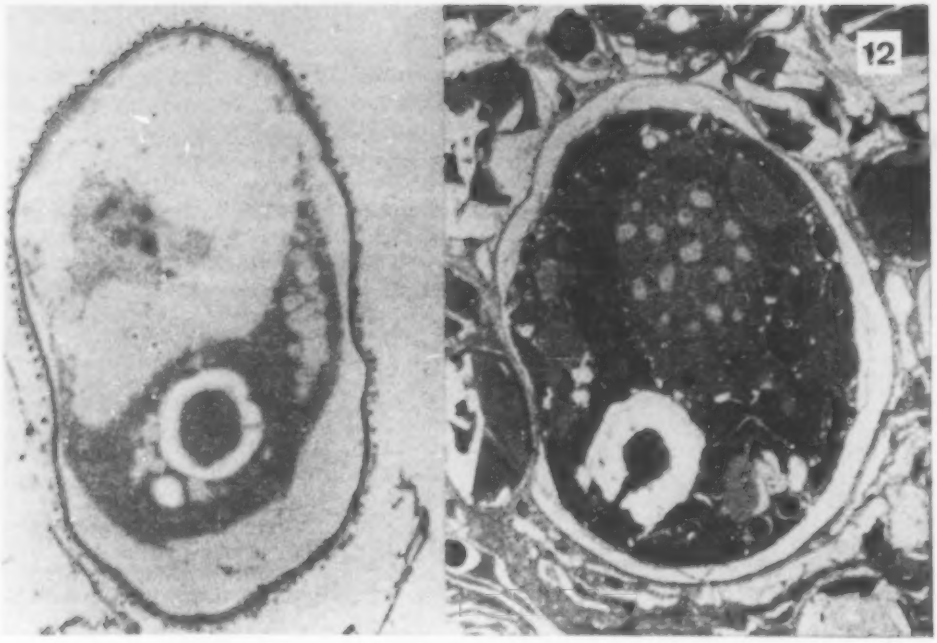


PLATE 12.—Photo taken with an electron transmission microscope of zooxanthellae from the bladed fire coral (20,000 magnification). The zooxanthella on the right is normal; note the internal structures. The cell on the left is from a bleached specimen and is dead; note lack of internal structures. Material collected at Sand Key Reef, October 1983.

HEALTHY AND DISEASED ZOOXANTHELLA

This is an electronphotomicrograph taken with an electronmicrophotoscope at about 20,000 magnification showing a normal zooxanthella on the right filled with the typical intracellular structures. The one on the left was taken from the bleached coral. You can see there is virtually no internal structure in there. Some of these zooxanthellae cells are either being digested or they are degenerating within the coral tissue.

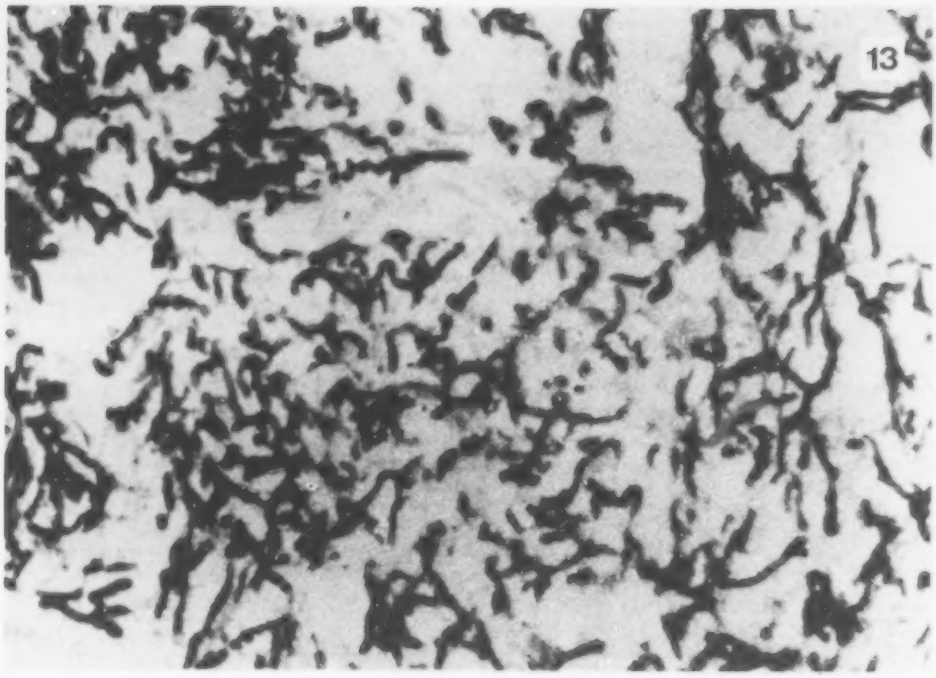


PLATE 13.—Decomposing tissues from the bladed fire coral. The black filaments are a fungi that are feeding on the tissues.

EFFECT OF FUNGAL HYPHAE

In 1983 we saw decomposition of tissue in place. These are fungal hyphae. They are decomposing the tissues of the fire coral.

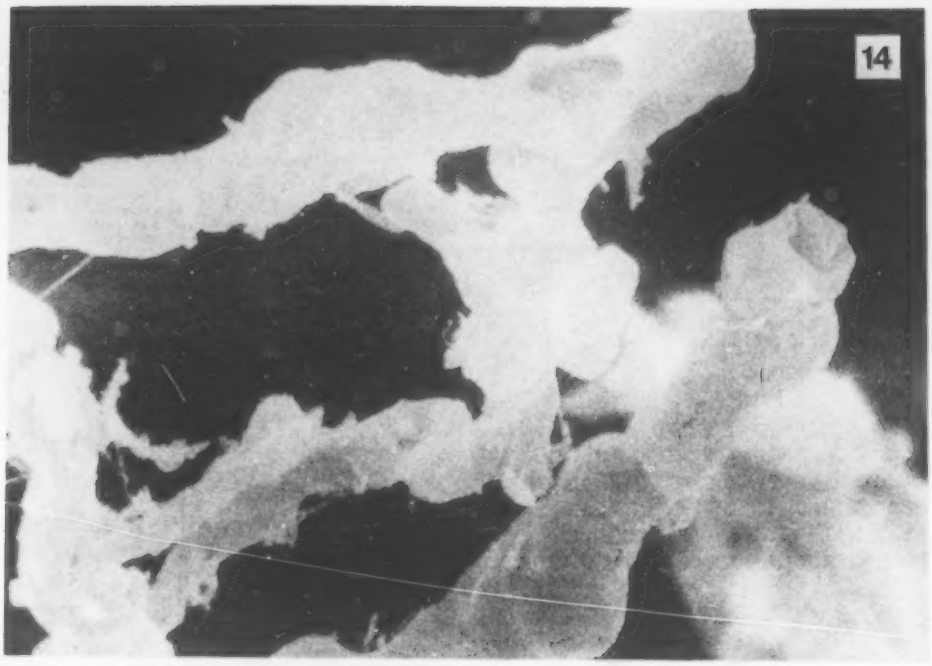


PLATE 14.—Scanning electron microscope photo of the fungal hyphae, 25,000 magnification.

MAGNIFICATION OF FUNGAL HYPHAE

This is an electronphotomicrograph of the microscopic fungi that are decomposing the coral tissues.

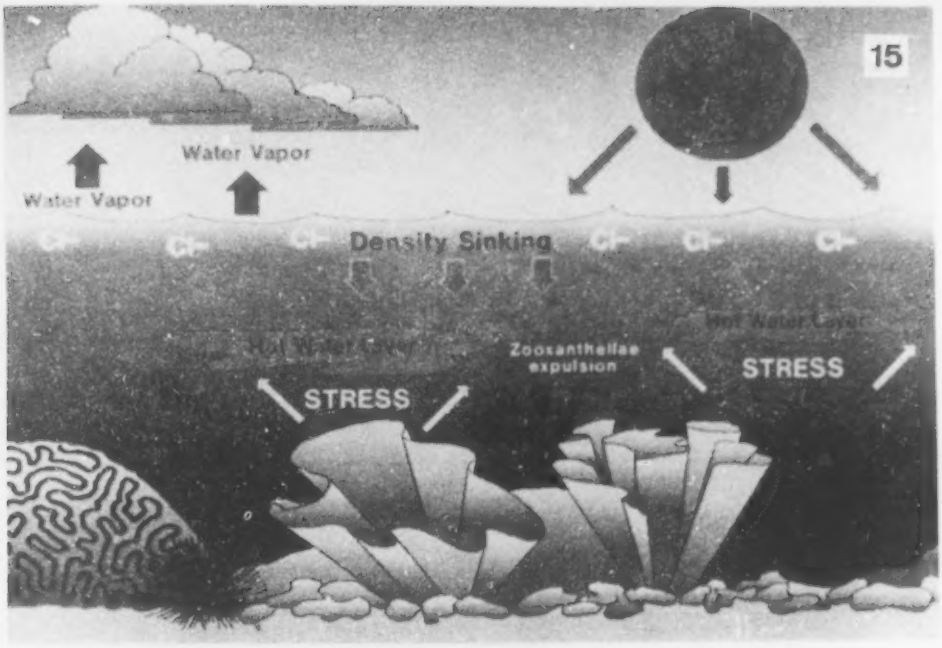


PLATE 15.—The hyperthermia model that was proposed by Jaap to explain the 1983 coral bleaching event in Florida.

KHYPERTHERMIA MODEL

The model in 1983 which described the etiology was related to heat stress: heating of the water column during a doldrum-like period. We also had sinking of hot saline water from the surface, and this brought stress down on to the reef, and it would be broken into layers or cells. The spotty nature of this event where some corals are affected and others are not, we theorize, was caused by cells of hot water that were randomly distributed, and they impacted some organisms but not others.

We collected information to see how much impact had occurred. The Elkhorn coral seemed to be totally immune in 1983 and even in this particular event (1987), we didn't see much bleaching of Elkhorn coral. In 1983, we monitored an area over a 7-month period to see how much mortality occurred.

PLATE 16.—Bladed fire coral that died following the 1983 event. Algae are rapidly colonizing on the dead coral skeleton.

BLADED FIRE CORAL

This photo displays what happened to that fire coral, if it did die, it is totally covered with algae very shortly after death. The first time it was sampled was on October 6, 1983 and the next time was May 6, 1984.

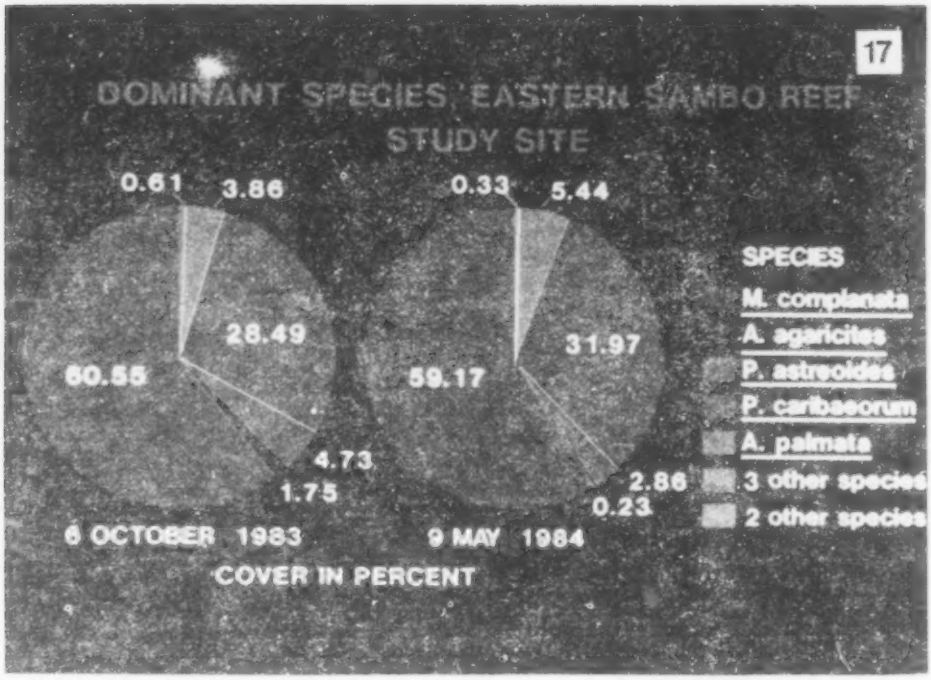


PLATE 17.—Comparison of percent of coral species abundance during and 7 months following the 1983 zooxanthellae expulsion.

CORAL SPECIE ABUNDANCE

You can see there is very little difference, the impact was not very significant. I would hasten to say that this was an event that was of a much smaller magnitude. There was only one sample, it does not represent what occurred in other habitats. It certainly may not be the situation in this particular case because of the widespread geographic and bathymetric nature of the event.

Thank you.

[The prepared statement of Walter C. Jaap follows:]

PREPARED STATEMENT OF WALTER C. JAAP

Biological Scientist III
Florida Department of Natural Resources
Bureau of Marine Research

INTRODUCTION

Corals are simple animals, distant cousins of the jellyfish; on the evolutionary scale they fall between the sponges and the flat worms. Corals construct the multidimensional limestone framework supporting the diversity of life found in the coral reef habitat.

Zooxanthellae are dinoflagellate algae (microscopic plants) that live symbiotically within the coral tissues (as well as several other groups of reef dwelling animals), comprising 40 to 50% of the coral complex biomass. They provide energy and oxygen to the coral animal via photosynthesis and receive nutritional compounds from the coral animal. Corals build limestone skeletons, primarily using the energy provided by the algae. Corals deprived of light grow at half the rate of the same species in light.

Massive coral bleaching is an unusual event, triggered by a major change in some physical or chemical environmental factor that stresses the reef. Zooxanthellae expulsions (coral bleaching) have been caused by drastic alterations in salinity, temperature (heat and cold), light and food deprivation, siltation, or extreme low tides exposing reef corals above the surface. The 1983 El Nino meterological event was a major cause of coral bleaching throughout the tropical Pacific, as are hurricanes and typhoons.

The precise mechanism that causes the zooxanthellae to be expelled is poorly understood. Corals naturally dispose of a few zooxanthellae (older, morbid, or dead individuals) all the time by ejecting them into the water column. Some species of coral may contain about 4 million zooxanthellae per square inch of surface, therefore to bleach, they must physically remove almost all the zooxanthellae from their tissues.

The ecological impact of a large coral bleaching event is an enigma, since few studies have focused attention at cellular, organism, or population level. Reports in the literature are mostly qualitative observations, because of the unpredictability of the events, pre-event baseline information is usually unavailable.

Many smaller organisms that live close to the coral surface feed on the mucus secreted by the corals. This mucus is rich in fats and oils and often contains considerable quantities of bacteria. populations. The mucus is generated by the combined efforts of both the zooxanthellae and corals. Following a zooxanthellae expulsion, mucus production, and coresponding energy to the food webs the mucus supports, will be a considerable reduced. Coral vitality also suffers because the zooxanthellae are a major source of energy to the animal.

In bleaching events of short duration, corals have been reported to regain near normal zooxanthellae populations in six to eight weeks. Mortality of corals under these circumstances has been minor. In cases where stress was severe, such as the eastern Pacific (Gulf of Panama and Galapagos Islands) in 1983, mortality has been 95% or greater.

In the Florida Keys reefs, prior zooxanthellae expulsions of sufficient magnitude to attract notice occurred in 1911, 1950s, 1966, 1973, and 1985. The 1973 and 1985 events were caused by doldrum weather conditions during late summer when ambient water temperatures were at a annual peak (about 86 F). When low tide occurred near midday, the shallow portions of the reef heated above 90 F, thus stressing the corals. We speculate (with some confidence) that the evaporative process during such events generates hot, saline, and perhaps anoxic stratified surface waters. The density gradient causes this "heavy" water to sink, stressing deeper reef communities. Coral bleaching in Florida occurs to at least 80 to 90 ft during the more severe events.

THE 1987 ZOOXANTHELLAE EXPULSION EVENT

As early as July 12, 1987, Florida Keys corals exhibited discoloring. The epicenter of the event was near Looe Key. Billy Causey, manager at Looe Key National Marine Sanctuary, reported that the corals began to loose color in shallow water first, then, as the event then moved deeper, the color loss became more severe. Components in the spur and groove community, fire coral, elkhorn coral, and the golden sea mat (Millepora complanata, Acropora palmata, and Palythoa caribaeorum) were heavily impacted. Some elkhorn corals died completely. On two occasions, Causey had an opportunity to make observations on reefs in the Key West area. He felt they did not exhibit bleaching as severe as he noted at Looe Key. In the Key Largo area, reefs began to discolor during the last week of August. John Halas, biologist at the Key Largo National Marine Sanctuary reported that the true bleaching began about the first of September. The pattern was similar to that reported by Causey at Looe Key. By October bleaching was reported on from Hollywood, Florida to Key West and probably to the Dry Tortugas. This is the most extensive geographic range of any recent zooxanthellae expulsion in Florida. During the same period of time, we began to receive reports of coral bleaching from scientists and recreational divers from other areas in the Caribbean. The reports do not provide the first incidence of discoloring, but do provide information on geographic distribution.information. The following table provides a summary of these reports.

Location	Month	Observer
Bermuda	June	Flagg
Grand Cayman	June	Flagg
Cartagena Colombia	July	Lang
Jamaica, north coat	July	Lang
Puerto Rico		Williams
St. John, USVI		Williams
St. Croix, USVI		Williams
Cozumel, Mexico	Sept 20	Flagg
Green Turtle Cay	Sept	Flagg
Grand Bahama Island	Sept	Flagg
Marsh Harbor, Bahamas	Sept	Flagg
Little Cayman, Island	Oct	Clark
Lee Stocking Island	Oct	Lang
Flower Garden Banks	Oct	Unknown
Florida, Looe Key	July	Causey
Florida, Key Largo	August	Halas

The depths where bleaching was seen ranged from near the surface to 120 ft. In most cases, the surveys were not systematic so there is only a perception on the part of an individual diver. At Lee Stocking Island, Bahamas, Bob Wicklund saw bleached corals and sponges as deep as 240 ft.

Caribbean reports include bleached sponges, anemones,

octocorals, hydrocorals, and stony corals, with some mortality. A number of observers reported that they felt water temperature was not abnormally hot when they observed the bleached animals.

In summary, the event extended from Bermuda to the southern reaches of the Caribbean Sea, Lesser and Greater Antilles, Bahamas, Florida, and the northern Gulf of Mexico. The earliest reports were in June and continued through September and early October.

SUMMARY OF OBSERVATIONS CONDUCTED OFF KEY LARGO, 7, 8, 11 OCTOBER 1987.

FRENCH REEF

Observations were made to depths exceeding 80 ft. Down to 60 ft nearly every coral colony was bleached or partially bleached. Water temperature was 84 F and uniform from the surface downward (no stratification to the bottom at 80 ft). The large haystack size star coral colonies (Montastraea annularis) with a pillar growth form showed bleaching similar to that seen by Jaap during 1983 off Key West. The lower concavities or valleys were bleached totally white, whereas the pillars were only partially discolored or retained most of their color.

To test the viability of Millepora (fire coral), I rubbed my wrist aganist the coral surface. I felt no pain as under normal conditions. Apparently the the stinging apparatus in the fire coral (nematocyst) was no longer functional.

Bleaching was very spotty between 60 and 80 ft. For example, here two colonies of Diploria strigosa displayed contrasting results; one colony could totally bone white and the other normally colored or only slightly discolored.

The following was observed:

Siderastrea siderea - Bleached, transparent to lilac in color.

Agaricia agaricites - Most colonies were very bleached; some in deeper water were mottled with a zebra pattern of brown and white.

Meandrina meandrites - Few colonies seen, most were unaffected.

Acropora cervicornis - Rare in the area, a clump seen at 62 ft appeared normal.

Montastraea cavernosa - Most colonies were normal with a few slightly discolored.

Montastraea annularis - Almost every colony seen was bleached or discolored or a combination of the two. As noted, small valleys tended to be more discolored than pinnacles.

Diploria strigosa - Uncommon; equal numbers were normal or bleached.

Dichocoenia stokesii - Rare; an individual at 45 ft was unaffected.

Madracis decactis - Slight discoloration.
Porites porites - Common; colonies were discolored and/or bleached.

GRECIAN ROCKS 5 to 15 ft deep.

Collections were made for histological evaluation. In this shallow reef habitat, almost every individual fire coral (Millepora spp.) and golden sea mat (Palythoa) expressed some degree of discoloration. Some fire coral colonies appeared dead. Most of the elkhorn corals (Acropora palmata) seemed unaffected and appeared a normal dark brown. In deeper portions of Grecian Rocks Reef, star and brain corals were very discolored or totally bleached. John Halas and I photographed and videotaped an area near buoy number 2.

The coral bleaching in Florida began in July near Looe Key and progressed northeast and southwest. The etiology appears to fit the hyperthermia model. Calm conditions prevailed. I speculate that heated water was the most probable cause (several individuals reported water temperatures were above 90 F). It would be difficult to suggest another mechanism that would act contemporanously throughout the Caribbean basin, since waterborn diseases require more than six months to move from Panama to Florida. Intense solar radiation (ultra violet or X ray) would not extend to sufficient depths to impact corals at 100 ft.

There may be a synergistic relationship between hyperthermia and nutrient enrichment or associated trace metal, pesticide, and PCBs originating from urban runoff. Reefs off the Florida Keys and off Colombia were strongly affected by this event. Both areas are heavily populated, and nearshore waters are contaminated to some extent with urban and agricultural runoff.

El Nino events often impact reefs in the tropical Pacific. During the 1983 El Nino reefs suffered major catastrophies due to hyperthermia and tidal emergence. In the Atlantic, there is a slight casual correlation between El Nino events and fewer hurricanes. There may be other ways that an El Nino might influence reefs in the Caribbean. This topic may be worthy of further examination.

RECOMMENDATIONS

1. Refine within the information available a chronology of the 1987 event. I understand that people at the University of Puerto Rico have begun to do this.

2. Short-term research projects that would aid in understanding the event and its ecological consequences include:

a. Community structure evaluation with photographic techniques (Done, 1981). This would provide some perspective of mortality. The effort would need to begin immediately or seek to interface with existing studies that have extensive baseline information on reefs that were impacted.

b. Histological examination of impacted corals to evaluate pathogens, reproductive status, and tissue health.

c. Physiological research to reevaluate the older information on coral tolerance to temperature, salinity, oxygen, pH, trace metals, pesticides, nutrient enrichment, and other pollutants such as PCBs, plasticizing agents, and hydrocarbon chemicals.

d. A through study of oceanography and water quality in the Florida Keys region to identify oceanographic patterns and determine if poor water quality contributes to the bleaching.

3. Future contingency plans:

a. Designate and support a regional institution or organization

as a coordinating agency to receive information and evaluate the need to mobilize response and prioritize research. For example, since 1983, we have experienced urchin disease, staghorn coral disease, general coral bleaching, and fish kills in the Caribbean basin. Due to poor communication, the scientific community often remained unaware of these events until it was to late to mobilize proper reseach effort.

b. Improve and support the monitoring network in the Caribbean basin so there is rapid reporting of marine phenomena. This should include modest recording of environmental data. The Island Association of Marine Laboratories is the ideal organization way to pursue this effort.

c. Support development of regional response teams that could be deployed to collect data and evaluate phenomena if the magnitude of the event warrants such a response. An infrastructure and funding would be needed to support this effort.

I include two publications that discuss previous zooxanthellae expulsions in Florida.

FLORIDA REEF MANAGEMENT CONCERNS

This bleaching event points out the environmental management limitations that currently exist in the Florida Keys Coral Reef Tract. The responsibilities are fragmented into Florida and Federal zones of management. There are a multitude of federal and state agencies that have reponsibilities for some portion of the reef resources. In general, reefs off the upper and middle Keys are under federal jurisdiction, while those off Key West are under Florida jurisdiction. The responsibilities are fragmented into the areas of environmental quality, fisheries, shipping and marine safety, mineral and petroleum exploration and exploitation, and mosquito control. This management structure leads to duplication of effort, poor cooperation and coordination, and is generally unresponsive to emergencies because of no planning for contingincies. The management units rate reef related issues a low priority for funding and personnel deployment. The following describes how the Australian Commonwealth and Queensland state governments deal with reef management in the Australian Great Barrier Reef system.

State of Florida

Department of Natural Resources

Interoffice Memorandum

DATE: May 26, 1987

TO: Karen Steidinger

THRU: Tom Perkins

FROM: Walt Jaap

SUBJECT: Australian Reef Management

The Great Barrier Reef off the eastern coast of Queensland, Australia, is the world's largest coral reef, extending over 230,000 sqare kilometers along 2300 km of coastline. Over 2100 individual reefs make up the main barrier, and 540 high islands have significant fringing reefs.

The Australian commonwealth government passed legislation making the Great Barrier Reef (GBR) a national park, and established the Great Barrier Reef Marine Park Authority to establish policy and determine research needs. The Authority is a multidisciplinary body of experts that advises and provides recommendations to the commonwealth and Queensland governments. While the reef is an Australian resource that has passionate national support, the GBR is jointly managed and administered by agreement between the commonwealth government and the state of Queensland. The GBR Marine Park Authority develops policies for comprehensive management, and daily operations are the responsibility of the Queensland National Parks and Wildlife Service (QNP&WS). They have stations, boats, and aircraft for monitoring the reefs and enforcing rules. The Australian reef management program is outlined in several articles that appeared in Coral Reef Symposia and in reef brochures that I obtained on a visit to Heron Island in 1985. I can provide these upon request.

Reef management in the GBR uses a zoning strategy that balances human needs with reef conservation. For example, spearfishing is allowed in some areas, but is only permissible with fins, mask and snorkel. Spearfishing by SCUBA is not allowed. Certain reefs are set apart for special purposes. In the Capricorn section of the GBR, from Rockhampton to Bundaberg, 70% of the reef is zoned for general use. In the central core area (see map) shipping and trawling are prohibited. One Tree Island Reef is set aside exclusively for research. Wreck Island Reef and its surrounding waters are a preservation zone to be undisturbed by man. Llewellyn, Heron Island, and Wistari Reefs are open to visitors, but collecting is not permitted.

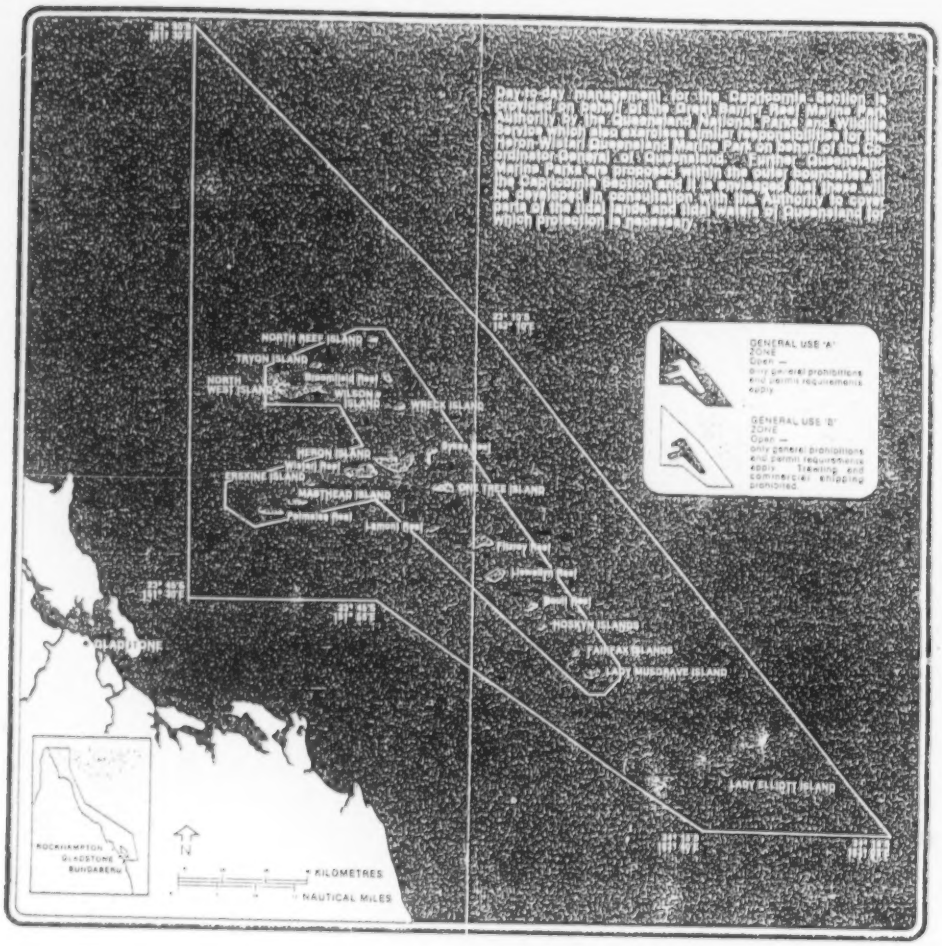
Permits must be obtained to collect anything from the waters of the GBR. The QNP&WS also controls issuance of permits for research, tourist cruise ships, educational programs, mooring facilities, fishing with certain gear, aircraft operations, use of hovercraft, and discharge of wastes. All exploration for petroleum and minerals is banned from the GBR. The QNP&WS has the authority to remove shipwrecks. Furthermore, they have the authority to close certain sections of the reef during breeding seasons for certain birds and turtles.

The zoning process works well in providing the necessary control for use by various conflicting groups. A high priority of the zoning plan has left development of remote areas that rarely see human influence for consideration by future generations. The major focus of the QNP&WS on the GBR is on regions with considerable exploitation and development. An example of the ability of this cooperative management system to react punctually to an issue is the potatoe cod conflict at Lizard Island. The potatoe cod, Epinephelus tukula, is a large serranid similar to our jewfish. A school of these fish was found on a reef near Lizard Island. The large fish became very tame as divers fed and photographed them. Even though the resort at Lizard Island caters to both divers and fishermen, the reef was zoned to allow no fishing to protect the cod from possible harm.

Could Florida and the federal government develop a reef management system similar to that of the Australians? I suggest that it would be worth the effort to try in order to at least coordinate the fragmented infrastructure that attempts to

manage the reef resources off southeast Florida today. A first step would be to call for a meeting of all state and federal agencies with statutory or mandatory responsibilities for the reefs. This group, through a series of meetings, could develop management goals through an ecosystem approach that should be implemented for comprehensive management of reef resources. For the time being, we could refer to this body as the Florida Reef Advisory Committee. A second goal would be for Florida to come to an agreement with the federal government to form a policy-making advisory group similar to the Great Barrier Reef Marine Park Authority.

Ideally, it would be best to have a single agency responsible for surveillance and enforcement of a set of consistent rules throughout the reef tract. It will take a great deal of effort to attain this. In the interim, we should work toward establishing consistent regulations for enforcement by all local, state and federal officers throughout the entire management area.



RESCREEN & SQUARE HALFTONES

BULLETIN OF MARINE SCIENCE, 29(3): 414–422, 1979 CORAL REEF PAPER

OBSERVATIONS ON ZOOXANTHELLAE EXPULSION AT MIDDLE SAMBO REEF, FLORIDA KEYS

Walter C. Jaap

ABSTRACT

Large-scale discoloration of Middle Sambo reef, 7.8 km from Boca Chica Key, Monroe County, Florida, was investigated on September 26, 1973. Discoloration of organisms was generally confined to the reef flat. The hydrozoan coral *Millepora complanata* displayed greatest discoloration. Some *Acropora palmata*, *Montastraea annularis*, and *Palythoa* sp. colonies were mildly discolored. Corals were still viable.

Calm weather, high ambient temperatures, and low tides at midday are believed to have caused water temperature elevation sufficient to produce thermal stress, thereby causing expulsion of endosymbiotic algae, *Gymnodinium microadriaticum*, with consequent discoloration of cnidarian hosts. Most organisms regained normal color within 6 weeks. Reports of similar coral discoloration incidents are reviewed. Short periods of thermal stress appear to have little lasting effect on shallow reef cnidarian communities.

On September 25, 1973, an officer of the Florida Marine Patrol reported discolored and bleached corals at Middle Sambo reef, a fringing bank reef, 24°29.4′N, 81°40.5′W, or about 7.8 km (4.2 nmi) from the south shore of Boca Chica Key in Monroe County (Fig. 1). I was sent by the Florida Department of Natural Resources Marine Research Laboratory (FDNRMRL) to investigate and conduct a snorkeling and scuba reconnaissance of the reef on September 26 and 27. The shallow flat has poor coral development due to exposure to environmental extremes; heavy seas break over it during storms and portions are emergent during some spring tides. Depth of the flat is less than 1 m (2 ft; National Ocean Survey [NOS] chart, 854, 1972). Conspicuous benthic organisms inhabiting the reef flat include: *Padina* sp., *Halimeda* sp., Corallinaceae, *Millepora complanata* (Lamarck, 1816) [fire coral], *Millepora* sp. (encrusting form), small stunted colonies of *Gorgonia ventalina* Linné, 1758 [sea fan], *Acropora palmata* (Lamarck, 1816) [elkhorn coral], *Favia fragum* (Esper, 1795) [star coral], *Montastraea annularis* (Ellis and Solander, 1786) [common star coral], and *Palythoa* sp.

Observations revealed random occurrence of mottled discoloration among hermatypic organisms inhabiting the reef flat; however, deeper regions of the reef, the spur and groove tract, and the area farther seaward displayed little evidence of discoloration. *Millepora complanata* showed the greatest incidence of discoloration; terminal fronds were colorless white, while basal portions of the same colonies displayed typical coloration (Fig. 2). *Acropora palmata* (Fig. 3), *Montastraea annularis*, and *Palythoa* sp. were affected but not as severely. The affected corals were visually inspected and appeared viable. *Acropora palmata* polyps were extended and undulating; upon tactile stimulation, they retracted into their calices. Nematocysts from dactylzooids of *Millepora* spp. inflicted pain to my forearm and wrist areas. Goreau (1964) noted similar pain-inducing qualities for discolored *Millepora* in Jamaica. Pain infliction by discolored *Millepora* colonies may indicate that they still possess functional feeding and defensive mechanisms despite the loss of zooxanthellae.

Cause of discoloration was expulsion of zooxanthellae, the endosymbiotic algae found in tissues of hermatypic reef organisms (Yonge and Nicholls, 1931). Zooxanthellae found within endodermic epithelium of Scleractinia and Milleporina

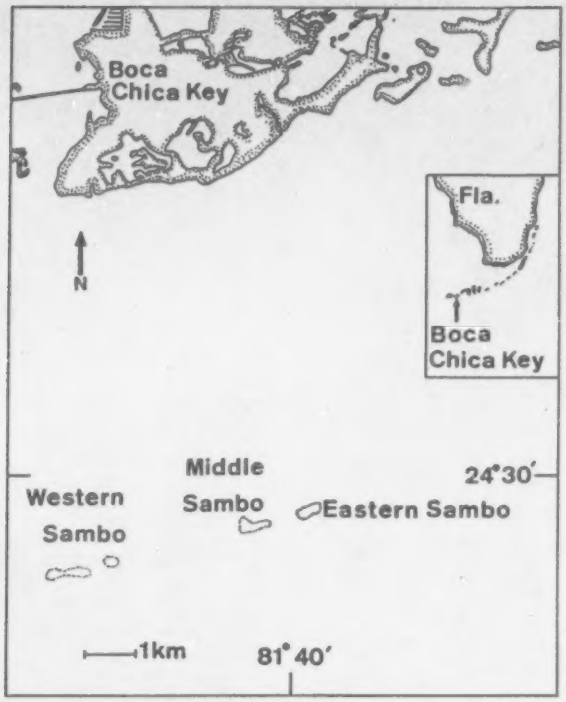


Figure 1. Location of Middle Sambo reef, NOS chart 1251, 1973.

are suspected to be *Gymnodinium microadriaticum* (Freudenthal) Taylor, 1971 (Dinophyceae). Dense concentrations of zooxanthellae are responsible for much of the color characteristics of scleractinian and milleporinian reef corals.

Natural factors causing reef coral discolorations, damage, or death include waves generated by hurricanes or cyclones, and salinity alteration from heavy rainfalls that often accompany tropical storms (the runoff frequently carries silt and debris from the adjacent land masses). Hurricane Flora deposited 550 mm of rain on Port Royal, Jamaica, in October, 1963, causing massive zooxanthellae expulsion among hermatypic organisms inhabiting shallow reefs (Goreau, 1964).

Thermal elevation of shallow reefs and tidal emergence also adversely affect shallow reef biota. Vaughan (1911) reported bleached heads of *Orbicella* (=*Montastraea*) *annularis* caused by tidal emergence at Dry Tortugas, Florida. Colonies of *Orbicella, Eusmilia fastigiata* (Pallas, 1766), *Diploria clivosa* (Ellis and Solander, 1786), and *Manicina areolata* (Linné, 1758) were killed by the exposure. In a subsequent incident, waters surrounding Bird Key, Dry Tortugas, were heated by several days of calm wind conditions resulting in mortalities among *Octopus, Fissurella,* and other mollusks, *Diadema,* and fishes; corals were injured (Mayer, 1918). Yonge and Nicholls (1931) reported expulsion of zooxanthellae from *Favia* and *Goniastrea* at Low Isles reef, Australia, due to natural thermal stress. They also reported expulsion due to laboratory induced stresses of heat, starvation, altered salinity, and total deprivation of light. *Acropora cervicornis* (Lamarck, 1816) transplanted inshore at Key Largo, Florida, during growth studies suffered zooxanthellae expulsion during late summer, but the symbionts were regenerated

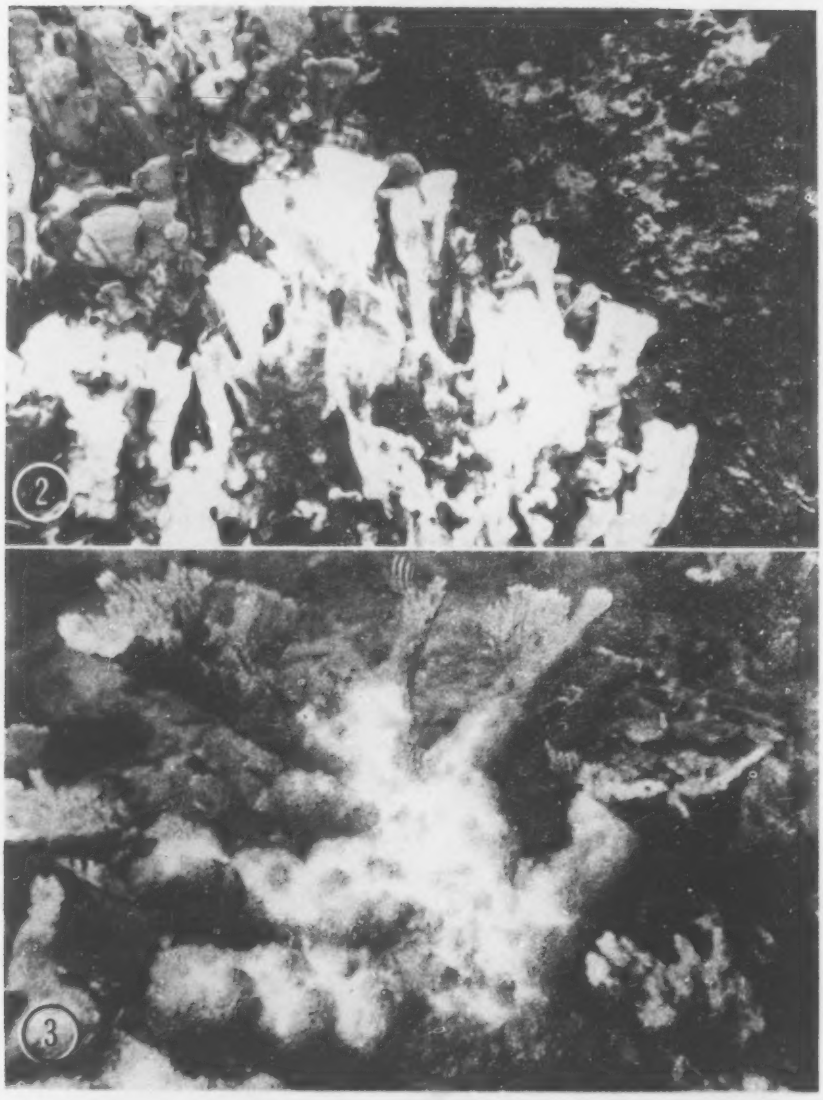


Figure 2. (Upper) Discolored *Millepora complanata* (Lamarck), Middle Sambo reef, September 26, 1973.
Figure 3. (Lower) Discolored *Acropora palmata* (Lamarck), Middle Sambo reef, September 26, 1973.

when cooler water temperatures returned (Shinn, 1966). Glynn (1968) reported massive mortalities among *Palythoa* and certain echinoids (*Tripneustes*, *Lytechinus*, and *Brissus*) at Caracoles reef flat, Puerto Rico, coincident with low tides at or near midday. Later observations revealed mortalities among corals of *Porites furcata* Lamarck, 1816 communities on the shallow reefs near Magueyes Island, Puerto Rico (Glynn, 1973). Loya (1972) reported scleractinian deaths on a reef flat in the Gulf of Eilat when synergistic meterological and astronomical

factors caused emergence of the reef flat during the heat of the day. Jokiel and Coles (1974), Coles (1975), Purkerson (1973), and Jones et al. (1976) reported thermal addition from power plant cooling water discharge caused zooxanthellae expulsion and mortality among corals (in order cited, Kahe, Hawaii, [first two]; Card Sound, Florida; and Tanguisson, Guam.

Conversely, seasonal loss of zooxanthellae in *Oculina* sp. and *Solenastrea hyades* (Dana, 1846) caused by reduced temperature in North Carolina has been noted by J. M. Wells (personal communication). In vitro thermal tolerance studies on *Pocillopora damicornis* (Linné), *Montipora verrucosa* (Lamarck) and *Porites compressa* Dana from Hawaii and Eniwetok indicate these species will expel their zooxanthellae at temperature below 21°C (Coles, 1973). Hudson et al. (1976) postulated that chilled water and other undetermined factors caused the death of reef corals at Hen and Chickens patch reef, 3.4 km (1.8 nmi) off Plantation Key, Florida.

The reported expulsion mechanism is concentration of zooxanthellae in the absorptive region of the mesenterial filaments; rejection occurs via the coelenteron; in some cases, algae cells are ejected in wafts of mucus (Yonge and Nicholls, 1931; Coles, 1973).

Expulsion of zooxanthellae is thought to be caused by the same factors influencing coral tissue metabolism. Yonge and Nicholls (1931) state that lowered metabolism of the host caused by stress reduces the available supply of nutrients (primarily nitrites, nitrates, phosphates, sulfates, and CO_2) for algal symbionts. Mayer (1918), commenting on the toxic effect of heat on stony corals, felt that carbonic acid accumulation and pH alteration in tissues caused the mortality. Heat exposure increases viscosity of cellular protoplasm (Gunter, 1957). Coles (1973) noted temperature increases resulted in increased coral-zooxanthellae respiration, gross zooxanthellae photosynthetic production and reduction in gross production/respiration ratios in Hawaiian species of *P. damicornis*, *M. verrucosa*, and *P. compressa*. The ratio reduction was interpreted to indicate that some metabolic wastes were not being utilized in the photosynthetic process by the zooxanthellae. Muscatine (1971) offered several hypotheses regarding possible triggering mechanisms of zooxanthellae expulsion. He suggested that a decrease in space caused by atrophied host tissues during heat-salinity stresses may stimulate rejection of symbionts or that stressed coral tissues may limit availability of nutrients thus starving zooxanthellae. Yonge (1963) and Taylor (1973) suggested that nitrogen and phosphorus are the limiting factors governing zooxanthellae growth. Host tissues may secrete a specific substance or substances inhibiting the physiology of zooxanthellae, or to carry this somehwat further, the substance or substances may alter the zooxanthellae environment such that it becomes intolerable.

Stress-inducing conditions at Middle Sambo are believed to be the synergistic effect of low tides at or near midday coincident with calm wind conditions during the warmest time of year. The Key West area experiences a mixture of semidiurnal and daily tides (U.S. Department of Commerce, 1972a). Tidal ranges at Middle Sambo are similar to those at Key West, 0.4 m (1.3 ft) and 0.5 m (1.8 ft) during spring tides; low tide occurs about 50 min and high tide about 62 min earlier than at Key West (S. Berkman, personal communication). Spring tide occurred September 12 and the autumnal equinox fell on September 23 (U.S. Department of Commerce, 1972a). Daylight tides at Key West, 17 to 24 September, are depicted in Figure 4.

There was a change in pattern from midday high tides to midday low tides from 17 to 22 September (Fig. 4); water level was below the mean low water reference

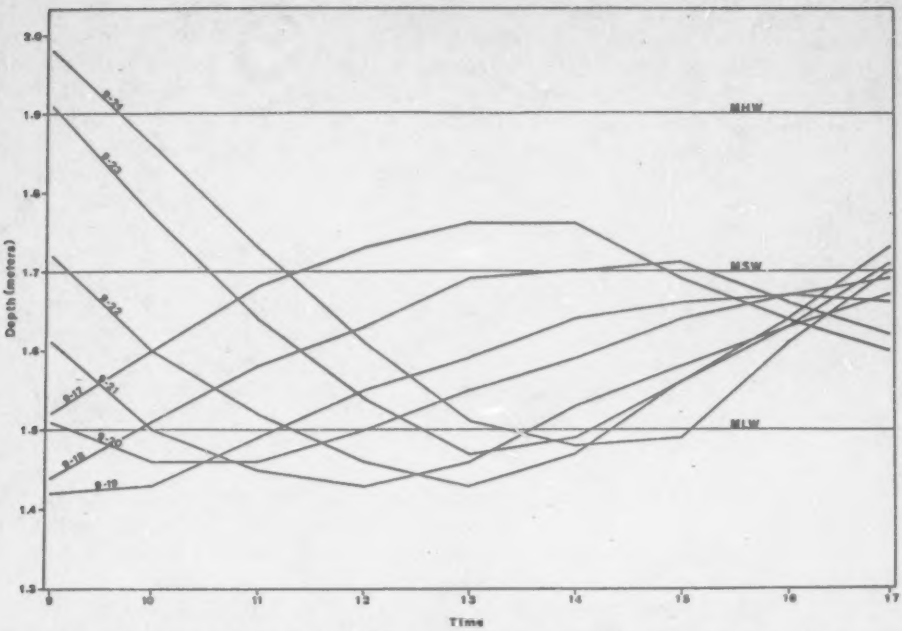


Figure 4. Tidal heights, 0900 to 1700 h, Key West, Florida, September 17 to 24, 1973. MHW: mean high water, MSW: mean standard water, MLW: mean low water. Source: NOS, NOAA.

mark (1.5 m) 50 to 67% of the midday period (1100 h to 1400 h) from 19 to 24 September. Tidal range is moderated by the equinox (Fairbridge, 1966); range was minimal, 0.23 m (9 in) on September 19 and 20. Lowest water levels (1.43 m) occurred at 1000 h (September 19), 1200 h (September 21), and 1300 h (September 22). Although the above data were reported from the Key West recording station located in the harbor area, a similar tidal range (with a time difference of one hour earlier) would not appreciably alter the tidal pattern at Middle Sambo.

Peak solar radiation is reported to occur from 0900 h to 1500 h in Florida and Jamaica (Barnes and Taylor, 1973). Hanson and Poindexter (1972) reported on several aspects of solar radiation near Pacific and Elbow reefs off Key Largo, Florida, during winter and spring of 1971. They found transmittance was greatest at solar noon; albedo was greater in early morning and late afternoon. Peak solar energy on the water surface occurred from 1000 h to 1400 h; most of the energy was expended in warming the water column.

United States Coast Pilot (U.S. Department of Commerce, 1972b) reports that mean surface water temperature for Key West is 29.7°C, prevailing winds are ESE, averaging 16.7 km/h, and a 66% potential for cloudless skies exists in September. Meterological data provided by the National Climatic Center (NOAA) for the Key West weather station (located 11.5 km, 310° from the affected reef) show air temperatures ranged from 25.0 to 31.6°C from 0900 h September 19, through 1700 h September 24, 1973. Maximum air temperature occurred at 1400 h on September 20 (Fig. 5). Wind direction was variable; hourly vectors for the same time period show ENE to ESE (67.6 to 112.5°) winds dominated 32.7% of the time. Wind has an important cooling effect on shallow reef flats and low velocities ranging from 0 to 25.9 km/h (mean = 11.3 km/h) prevailed at the time.

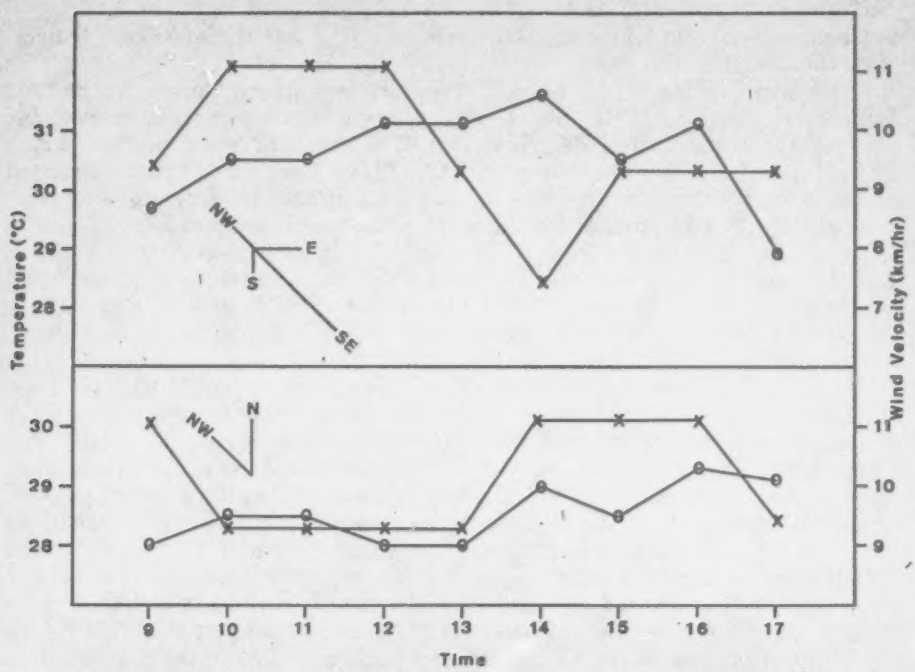


Figure 5. Air temperatures (O), wind velocities (×), and wind directions, 0900 to 1700 h, September 19 (bottom) and 20 (top), 1973. Source: National Climatic Center, Key West, weather station.

Glynn (1973) noted a rapid rise in seawater temperature during periods of low wind velocity. Mean Key West wind velocity from 19 to 24 September 1973 was 5.4 km/h less than the average value given in the U.S. Coast Pilot. Depression of midday air temperature noted for the time in question was partially the result of rain squalls.

I revisited Middle Sambo reef November 6, 1973, 6 weeks after the first observations. Most affected organisms had recovered their natural coloration; only *Millepora complanata* displayed minor symptoms of discoloration. Goreau (1964) noted *Millepora* required more than 14.5 weeks to regain its normal color; most other hermatypic organisms regained their normal complement of zooxanthellae in 6 to 10 weeks. Yonge and Nicholls (1931) reported 10.5 weeks for three species of *Favia* and one *Goniastrea* to regain their zooxanthellae after expulsion due to natural thermal stress.

Scleractinian reef corals are reported to flourish in temperatures of 25 to 29°C (Wells, 1956, 1957; Stoddart, 1969); however, under unusual conditions, some are reported to survive 40°C (Kinsman, 1964). Upper thermal limits were laboratory-determined for 18 species of Florida scleractinian corals (Mayer, 1914). Tolerance ranges for individual species were variable; *Acropora palmata* had a lethal temperature of 35.8°C; polyp movement ceased at 34.7°C. In a later study, Mayer (1918) reported *Acropora muricata* (=*palmata*?) succumbed to heat stress at 34.7°C. Coles (1973) determined the minimum thermal limits for *M. verrucosa* to be 18 to 19°C, and the maximum 31 to 32°C, with optimum growth and other optimum physiological vital signs occurring at 27 to 28°C. Shinn (1966) reported zooxanthellae expulsion from *A. cervicornis* at or near 33.8°C at Key Largo in

September. Wells (in Kinsman, 1964) believed 32°C was the maximum temperature tolerable for *Acropora*.

Water temperature of the Florida reef tract is warmest during August and September (Vaughan, 1918; Shinn, 1966; computerized summary of available oceanographic data in one degree square 41 within modified Canadian square 1110, National Ocean Data Center, NOAA, 1974). Vaughan (1918) summarized seawater temperature data for Florida reef tract lighthouses from 1879 to 1899; at Sand Key, 20.7 km west of Middle Sambo, September temperatures (averaged for 10-day periods) ranged from 28.7 to 31.4°C with a mean of 30.0°C. Smith et al. (1950) reported monthly seawater temperatures ranging from 24.35 to 29.8°C between July, 1945 and June, 1946 at Pacific Reef off Old Rhodes Key. During 1961, maximum temperature at Margot Fish Shoal, off Elliot Key, was 30.5°C (Jones, 1963).

The ecological repercussion of zooxanthellae expulsion would be a decrease in calcification rates of the corals. Zooxanthellae are able to affect the rate of skeletogenesis of hermatypic reef corals (Goreau, 1959; Goreau and Goreau, 1959, 1960a, 1960b; Pearse and Muscatine, 1971; Vandermeulen et al. 1972; and Muscatine, 1973). Light-enhanced calcification is directly photosynthesis-dependent (Vandermeulen et al. 1972). In situ calcium uptake experiments on *Manicina areolata* with and without zooxanthellae show that the rate of calcium uptake by colonies possessing zooxanthellae was 19 times greater than colonies void of zooxanthellae (Goreau and Goreau, 1959). In vitro experiments indicated calcification is inhibited by thermal stress (Coles, 1973; Jones et al. 1976). In *A. cervicornis* transplanted by Shinn (1966) growth rate (i.e. calcification) ceased when zooxanthellae were expelled, but resumed growth when zooxanthellae were regained.

When zooxanthellae are regained in 6 to 10 weeks, the effect on coral growth is probably minimal. Sublethal effects were noted for *Pocillopora meandrina* Dana exposed to 31+°C; most specimens returned to normal during lower ambient temperatures (Coles, 1975). However, in cases of chronic zooxanthellae loss, growth was inhibited. Other facets of the biology of the organisms were probably also affected. Yonge and Nicholls (1931) reported colonies lacking zooxanthellae were less able to remove sediment from their tissues than those having the algal symbionts. In cases where thermal addition from power plant discharge was continuous, mortalities occurred among stony corals near the discharge area due to the long term exposure (Jokiel and Coles, 1974; Coles, 1975; Jones et al. 1976).

Meterological and tidal information and other reports of zooxanthellae expulsion indicate that the most probable cause of expulsion at Middle Sambo was solar-thermal elevation of water covering the shallow reef flat. I subsequently observed some evidence of zooxanthellae expulsion at Sand Key during August, 1974. Such occasional reactions are probably not uncommon during late summer, when conditions are optimal for causing heat stress, but they are evidently of short duration with little long-lasting effect upon the reef cnidarian communities.

Summary

On September 26, 1973, observations conducted on the shallow reef flat at Middle Sambo, near Key West, revealed varying degrees of discoloration among hermatypic reef organisms. Scleractinian reef corals, *Acropora palmata* (elk horn coral) and *Montastraea annularis* (common star coral), and the brachycnemian zooantharian *Palythoa* sp. displayed moderate discoloration; the hydrozoan fire coral *Millepora complanata*, exhibited a high degree of discoloration.

Affected organisms were viable, despite loss of dinoflagellate symbionts, *Gymnodinium microadriaticum*; polyps reacted upon tactile stimulation and *Millepora* dactylzooids discharged nematocysts. Observations 6 weeks later revealed almost complete recovery except for *Millepora complanata*.

Meterological and tidal data indicate the synergistic effect of low tides during midday from 19 to 24 September and high air temperature with variable low wind velocity produced elevated seawater temperature on the shallow reef flat, causing hermatypic organisms to expel zooxanthellae.

Such phenomena probably occur infrequently on shallow Florida Keys reefs, with little lasting effect.

NOTE ADDED IN PROOF: *Gymnodinium adriaticum* was recently transferred to *Zooxanthella* by Loeblich and Shirley (J. Mar. Biol. Ass. U.K., 59: 195).

ACKNOWLEDGMENTS

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ERRATA

PAGE	LINE	
421	11	READS: NOTE ADDED IN PROOF: Gymnodinium adriaticum was recently transferred to Zooxanthella by Loeblich and Shirley (J. Mar. Biol. Ass. U.K., 59: 195). SHOULD READ: NOTE ADDED IN PROOF: Gymnodinium microadriaticum was recently transferred to Zooxanthella by Loeblich and Shirley (J. Mar. Biol. Ass. U.K., 59: 195).
421	37	READS: midday, low water exposure in Puerto Rico. Mar. Biol. (N.Y.) 1: 226-243. SHOULD READ: midday, low water exposure in Puerto Rico. Mar. Biol. (Berl.) 1: 226-243.
421	39	READS: hydrography. Mar. Biol. (N.Y.) 20: 297-318. SHOULD READ: hydrography. Mar. Biol. (Berl.) 20: 297-318.
422	11	READS: Kinsman, D. 1964. Reef coral tolerance of high temperatures and salinities. Nature (Paris) 202(4939): SHOULD READ: Kinsman, D. 1964. Reef coral tolerance of high temperatures and salinities. Nature (Lond.) 202(4939):
422	14	READS: Mar. Biol. (N.Y.) 13: 100-123. SHOULD READ: Mar. Biol. (Berl.) 13: 100-123.
422	41	READS: on zooxanthellae in corals and other invertebrates. Mar. Biol. (N.Y.) 16: 185-191. SHOULD READ: on zooxanthellae in corals and other invertebrates. Mar. Biol. (Berl.) 16: 185-191.

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AN EPIDEMIC ZOOXANTHELLAE EXPULSION DURING 1983 IN THE LOWER FLORIDA KEYS CORAL REEFS : HYPERTHERMIC ETIOLOGY

UNE EXPULSION EPIDEMIQUE DE ZOOXANTHELLES EN 1983 DANS LES RECIFS CORALLIENS DU SUD DE LA FLORIDE : ETIOLOGIE HYPERTHERMIQUE

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ABSTRACT

Extensive reef coral zooxanthellae expulsion occurred from Key Largo to Dry Tortugas, Florida, during September 1983. Coral bleaching was intensive between Pelican Shoal and Sand Key Reef off Key West. Coral discoloration extended to depths exceeding 14 m but was especially severe in shallow (1-2 m) spur and groove habitats. Approximately 75-95% of all Millepora complanata and Palythoa caribaeorum were bone white, but most colonies remained viable. Affected M. complanata (bladed fire coral) retained the ability to inflict pain from dactylozooid nematocysts. Some individuals (5 to 10%) had fine algal growth indicating death on all or parts of their skeletons. Although 15 species of cnidarians, principally Scleractinia, were affected, some species (Madracis mirabilis, Porites porites, Montastraea cavernosa, Dendrogyra cylindrus) appeard to be immune. A quantitative sample at Eastern Sambo Reef on 6 October documented 11 species and 209 colonies; M. complanata comprised 32.5% of all colonies. Transmission electronmicrographs did not reveal epidemic pathogenic organisms in affected coral tissues. Warm, calm weather prior to the expulsion was conducive to elevated seawater temperature. A seawater thermograph deployed off Marquesas Key recorded temperatures of 32.3°C during the period.

A seven month post-event survey revealed that most hermatypic organisms had recovered normal color. Survival of hermatypic cnidarians was high. Twenty quadrats sampled during and seven months after the event were compared using classification analysis (Czekanowski's quantitative coefficient); mean similarity value among all quadrats was 0.69, and 12 of 20 quadrats had similarity values > 0.70. Values obtained using this technique in similar habitats generally ranged from .4 to .9 annually. The event is an example of a disturbance of intermediate frequency and magnitude controlling shallow reef communities.

RESUME

Des expulsions massives de zooxanthelles de coraux ont eu lieu de Key Largo à Dry Tortugas en Floride en Septembre 1983. Le blanchiment des coraux a été intensif entre Pelican Schoal et le récif de Sand Key au large de Key West. Le blanchiment des coraux s'est étendu à des profondeurs excédant 14 m mais a été particulièrement sévère en eau peu profonde dans la zone éperons-sillons (1-2m). Environ 75 à 95% de tous les Millepora complanata et Palythoa caribaeorum ont été blanchis mais la plupart des colonies restent viables. Les M. complanata affectés (les lames de coraux de feu) gardent la capacité d'infliger des brûlures à partir des nématocystes. Quelques individus (5-10%) arborent un fin recouvrement algal indiquant la mort de tout ou une partie de leur squelette. Bien que 15 espèces de Cnidaires, principalement des Scléractiniaires, aient été affectées, quelques autres (Madracis mirabilis, Porites porites, Montrastrea cavernosa, Dendrogyra cylindrus) apparaissent sauves. Un échantillon quantitatif à Eastern Sambo du 6 Octobre, révèle 11 espèces et 209 colonies. M. complanata compose 32.5% de toutes les colonies. La microscopie électronique à transmission ne révèle pas d'organisme pathogène dans les tissus altérés des coraux. La chaleur et le temps calme précédant l'expulsion des zooxanthelles a provoqué une élévation de la température des eaux. Un thermographe installé à Marquesas Key a révélé des températures de 32°3C au cours de cette période.

Une étude réalisée 7 mois après l'évènement a révélé que la plupart des organismes hermatypiques avaient retrouvé une couleur normale. La survie des Cnidaires hermatypiques est élevée. 20 quadrats pendant et 7 mois après l'évènement ont été comparés et analysés (coefficient quantitatif de Czekanowski). La valeur moyenne de similarité parmi tous les quadrats est de 0.69 et 12 des 20 quadrats ont des valeurs de similarité > 0.70. Les valeurs obtenues en utilisant cette technique dans des habitats similaires s'étendent en général de 0.4 à 0.9 annuellement. L'évènement observé est un exemple de perturbation de fréquence et de grandeur intermédiaire contrôlant les communautés récifales peu profondes.

INTRODUCTION

A major zooxanthellae expulsion occurred in Florida Keys coral reefs during early September 1983. Such events occur infrequently in Florida reef communities (Vaughan 1911; Mayer 1914; Shinn 1966; Jaap 1979) and other Caribbean areas (Goreau 1964; Glynn 1968). Although a great number of zooxanthellae expulsions were reported from tropical areas during 1982-1983, these were related to radical climate and oceanographic changes caused by a severe El Niño event (Glynn 1983; 1984a; 1984b; Coffroth et al. 1984; Lasker et al. 1984). Coral mortality was significant in the Gulf of Panama; Galapagos Islands; Moorea, French Polynesia; Nukunonu Atoll, Tokelau Islands; Paulau, Pari, Serbibu, and Karimunjawa Islands, Indonesia (Glynn 1984a; 1984b).

METHODS

A fixed wing single engine aircraft was used to survey reefs from Big Pine Key to Dry Tortugas following reports of coral discoloration. Visual observations supplemented by photography evaluated the geographic range of the phenomenon. Reef surveys were conducted in Key Largo National Marine Sanctuary (KLNMS) and off Key West using snorkle and scuba; observations were recorded on waterproof paper and documented with photography.

Samples of normal and blanched cnidarians (Palythoa caribaeorum, Millepora complanata, Madracis mirabilis, and Acropora palmata) were collected for histological studies. Specimens were preserved in Zenker's formalin fixative; histological techniques followed Yevich and Barszcz (1977). Other specimens of the same species were fixed in a gluteraldehyde, paraformaldehyde, and sodium cacodylate solution for transmission electron microscope (TEM) examination.

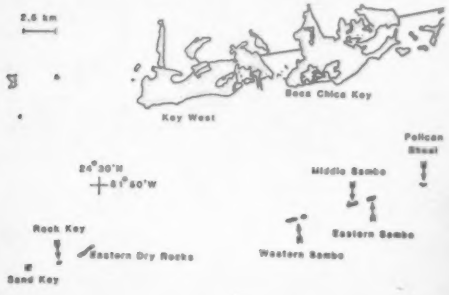

Figure 1. Area of severe zooxanthellae expulsion south of Key West, Florida.

A site at Eastern Sambo Reef selected for evaluation of community dynamics was located approximately 8 km S. of Boca Chica Key (Figure 1). The sampling site was located on a spur in 3 to 4 m depths. Sampling used reference stakes driven into the reef frame and secured with hydraulic cement. A metric fiberglass tape measure was extended 20 m between the stakes. A 1-m^2 quadrat was centered on the tape at each meter for censusing the Cnidaria within the quadrat. Quadrat maps were drawn (following Weinburg 1981) on 6 October 1983 and 9 May 1984. A Nikonos camera with 15 mm lens and 400 ISO color print film mounted on a unipod apparatus (Done 1983) was used to photograph the transect. Data were tabularized by date and analyzed for species abundance, frequency of occurrence, per cent abundance, density (mean and standard deviation per square meter), diversity (H') evenness (J'), and biological index (McCloskey 1970). Species area curves, classification, and ordination, all based upon species abundance, were processed with the SPARCR and ORDANA benthic analysis computer programs (Bloom et al. 1977); 4th root data transformation (Field et al. 1982) was performed before classification analysis. Czekanowski's quantitative coefficient (also known as Bray-Curtis) (Bloom 1981) with group average sorting was used to generate dendograms. Interstation linkages were plotted from coefficient values. Environmental data were received from the Key West weather station, U.S. Geological Survey Fisher Island Station, and the University of Miami.

DESCRIPTION OF THE PHENOMENON

Coral blanching in Florida occurred from off Elliott Key to Dry Tortugas, a distance of about 222 km. Impact was most severe off Key West: Pelican Shoals, Eastern, Middle, and Western Sambo, Eastern Dry Rocks, Rock Key, and Sand Key Reefs (Figure 1). Blanched coral was first reported on 3-4 September by divers, boaters, and fishermen from Key West.

Aerial surveys from 152 - 305 m altitude revealed that shallow spurs and reef flats were an abnormal white color. This was true for all reefs between and including Pelican Shoal and Sand Key. There were reports of blanched coral from Looe Key Reef and Dry Tortugas, but this could not be seen from the air.

Diving inspections disclosed that this zooxanthellae expulsion was significantly greater than the 1973 expulsion in the same area (Jaap 1979). From a distance, spurs looked like snow-draped ridges (Figure 2).

Figure 2. Blanched Millepora complanata in the spur and groove habitat, 1-2 m, Eastern Sambo Reef, 20 September 1983.

Close examination revealed that bladed fire coral (Millepora complanata) and golden sea mat (Palythoa caribaeorum), were bone white. Few individuals of either species exhibited normal golden-yellow color; many were blanched from base to tip. However, most blanched organisms were alive; M. complanata induced pain to forearm and wrist when touched, and Palythoa polyps were expanded and capable of retracting tentacles when stimulated.

Three degrees of zooxanthellae expulsion were observed. (1) Paling. The entire coralla was uniformly lighter than normal in color but not white. This was most frequently observed in Montastraea annularis, Siderastrea siderea, Colpophyllia natans, and Meandrina meandrites in the fore-reef area. (2) White spotting. Some portions of the coralla retained normal color, while other portions were contrastingly stark white (Figure 3). This was observed in a number of species but most frequently in Acropora palmata and M. annularis. (3) Total blanching. Complete loss of color was most frequently seen in the shallow spur and groove habitat. Species expressing this degree of discoloration were principally M. complanata, P. caribaeorum and some specimens of the octocoral, Briareum asbestinum.

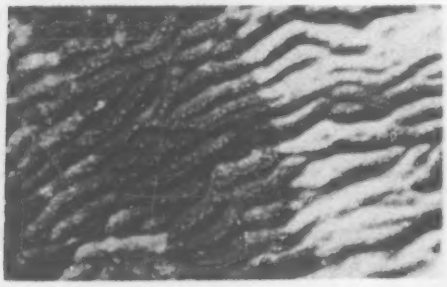

Figure 3. Spotty blanched condition in Agaricia agaricites, Sand Key Reef, 6 m, 5 October 1983.

Sixteen species of Cnidaria expelled zooxanthellae and six species appeared to be unaffected (Table 1).

Table 1. Cnidarians affected and unaffected during the 1983 Florida zooxanthellae expulsion.

I. Blanched species	
Palythoa caribaeorum	Millepora alcicornis
Meandrina meandrites	Millepora complanata
Briareum asbestinum	Siderastrea siderea
Montastraea annularis	Madracis decactis
Agaricia agaricites	Colpophyllia natans
Acropora palmata	Diploria strigosa
Acropora cervicornis	Diploria clivosa
Diploria labyrinthiformis	Porites astreoides

II. Species not discolored	
Ricordea florida	Eusmilia fastigiata
Madracis mirabilis	Porites porites
Montastraea cavernosa	Dendrogyra cylindrus

Surveys revealed blanched cnidarians to depths of 12 m, those at greatest depths usually occurring in pale or spotted conditions.

Millepora complanata at shallow reef areas in the Sambo group (Figure 1) exhibited >95% incidence of blanching. At Rock Key, Eastern Dry Rocks, and Sand Key Reefs, the incidence was reduced to about 75%. Mortality of M. complanata populations was estimated at 5 - 15% based on immediate blue-green algal colonization of the coralla.

Examinations at KLNMS revealed significantly less impact than that seen in the Key West area. Pale or spotted discoloration was commonly observed, but total discoloration was rare.

Histological examination of blanched and normally colored M. complanata indicated total loss of Symbiodinium microadriaticum (the endosymbiont alga) in blanched samples. Blanched specimens also contained abundant mucoid-polysaccharide material in the cytoplasm. Examination of normally colored M. complanata with TEM at 14,000 to 20,000 magnification revealed typically healthy complements of zooxanthellae (Figure 4), but blanched coral tissues contained degenerate S. microadriaticum (reduced or no chloroplasts, lack of lipids, and ruptured membranes) (Figure 5). Abnormal mitochondria and unidentified structures were observed in coral tissue of several blanched specimens. No pathogenic microorganisms were detected; however, fungal mycelium was observed in M. complanata and Madracis mirabilis tissues.

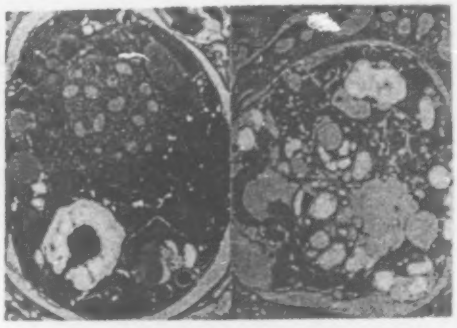

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Figure 4. Zooxanthella (Symbiodinium microadriaticum) from normally pigmented M. complanata, 20,200 magnification, Sand Key Reef, 1-2 m, 6 October 1983.

Figure 5. Degenerate zooxanthella from blanched M. complanata, 20,200 magnification, Eastern Sambo Reef, 1-2 m, 6 October 1983.

Observations conducted during May 1984 disclosed near total return of normal color to corals throughout the reef tract. Mass mortality had not occurred.

COMMUNITY STRUCTURE

Species area curves documented sufficient sample size to quantitatively assess community structure. Millepora complanata, A. agaricites, P. astreoides, and P. caribaeorum dominated the community, comprising 93.3% of the assemblage in October 1983. In May 1984, major changes had occurred in the abundance of dominant organisms. There was an increase of 155 colonies. The number of species increased by one, and colony density increased from 10.45 to 18.15/m^2. Millepora complanata increased from 68 to 162 colonies. Both diversity and evenness (H'and J') decreased.

Homogeneity was high among the 20 quadrats sampled in October 1983. Site group linkage documented 43 cases of similarity greater than 0.65, 19 cases greater than .80, and 10 cases greater than 0.90. A classification dendrogram (Figure 6) defined five site groups. However, further evaluation disclosed only four groups actually characterized by differences in dominant species. Porites astreoides dominated site group A; A. agaricites and P. astreoides dominated group B; M. complanata was the only species in group C, and, in association with several other species, dominated group D; and P. caribaeorum was the prominent species in group E.

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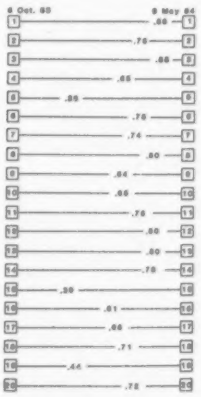

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Figure 6. Dendrogram of 20 quadrats, Eastern Sambo Reef, 6 October 1983, computed with Czekanowski's quantitative coefficient, 4th root data transformation, of species abundance with group average sorting; quadrat numbers to left of clusters. A = quadrats dominated by P. astreoides; B = quadrats dominated by P. astreoides or A. agaricites; C,D = quadrats dominated by M. complanata or M. complanata in association with other species; E = quadrats with P. caribaeorum dominating.

Figure 7. Temporal similarity of 20 quadrats sampled 6 October 1983 and 9 May 1983 as indicated by Czekanowski's quantitative coefficient. Transect numbers within squares; coefficient values derived from species abundance and 4th root transformation.

Classification comparison of the 20 quadrats between October 1983 and May 1984 disclosed a mean similarity value of 0.69±0.14 (Figure 7). Only three quadrats exhibited radical change, expressing similarity values of 0.39 (2 cases) and 0.44. Inspection of species abundances in these quadrats showed there had been significant changes between October and May. For example, the initial assemblage in one quadrat was comprised of 5 M. complanata and 3 P. caribaeorum. Seven months later, that quadrat contained 11 M. complanata, 10 A. agaricites, 2 P. astreoides and 3 P. caribaeorum. These changes were due to recruitment by larval settlement and fragmentation propagation. Differential mortality also contributed to the increase of discrete M. complanata colonies.

ENVIRONMENTAL CONDITIONS AND ETIOLOGY

Air and seawater temperatures were above normal compared to historical data; wind velocity was below normal (Table 2).

Table 2. Environmental parameters for Key West and Sand Key for September.

Parameter	Observed	Historical norms*
Air temperature (°C)		
Range	27.2-30.3	25.9-30.1
Mean	28.5	27.9
Wind speed (km/hr)		
Range	0-33	0-61
Mean	13.8	16.1
Seawater temperature (°C)		
Range	29.0-32.3(M;HC)	28.7-31.2
Mean	30.5(M), 31.6(HC)	30.3

*Historical sources: Climate (U.S. Dept. of Commerce 1982b), Seawater, 1879-1907 (Vaughan 1918). M: Marquesas thermograph; HC Hen and Chickens thermograph.

Hourly mean air temperature from 25 August until 10 September at Key West ranged from 27.2± 1.2°C (± 1 Std. dev.) at 05:00 to 30.3± 0.7°C at 14:00. Wind velocities ranged from 0 to 33 km/hr with a mean of 13.8± 3.5 km/hr. Several days of relatively calm wind were noted, the mean velocity on 29 August was 7.1±4.7 km/hr. Wind direction was SE and ESE during most of the period. Cloud cover averaged about 66% and was variable. Daily rainfall ranged from 0 to 36 mm but averaged only 5 mm/day (meterological information summarized from Key West weather station data). There are no seawater temperature data from the Pelican Shoal - Sand Key area for August and September 1983, but seawater temperatures from Florida Bay, Big Pine Channel were approximately 33°C during late August and early September (B. Causey, personal communication). A thermograph deployed at Marquesas Key, 31 km west of Sand Key, in 1.5 m depth recorded hourly temperatures ranging from 29.0 to 32.3°C from 7 September through 18 September; mean value was 30.5±0.7°C. A thermograph deployed at Hen and Chickens Reef, 6.1 m, 143 km NE of Sand Key, off Plantation Key recorded temperatures of 31.4 to 32.2°C between

31 August and 14 September. Low tides occurred at Sand Key between 12:00 and 17:00 from 25 to 28 August and 3 to 10 September. (U.S. Dept. of Commerce 1982a). Predicted tidal heights for these low tides were datum to 18 cm above datum. High tides for the same two periods were predicted at 30 to 33 cm above datum.

The zooxanthellae expulsion in the Florida Keys during 1983 was most probably the result of elevated temperature. Other environmental parameters contributed directly or indirectly to heating of the water column. Clear sky, low tides at or near midday, and low wind velocities probably all contributed to the event. Doldrum conditions that existed during the period are not unusual during late summer. The water was near calm with very slight swells during the surveys. A local fisherman commented that there had been "dirty water" along the reefs for several weeks during late August (P. Horton, personal communication). Ultraviolet radiation may have added to the stress during midday low tides (Jokiel 1980).

The depth of occurrence (to >12 m) of the blanching is possibly explained by density sinking of heated surface waters. During doldrum periods, evaporation creates hypersaline surface layers which maintain their integrity and slowly sink. Some mixing with cooler subsurface waters occurs, but pockets of hot hypersaline water can reach the bottom and make contact with cnidarians and other benthos. This water probably has other unfavorable characteristics, i.e., low oxygen saturation, high chlorinity, and reduced pH. The spotty expression of zooxanthellae expulsion may be explained by prolonged contact of hyperthermal-hypersaline water with portions of cnidarian colonies. In shallower waters, it is probable that corals were bathed in a more uniform mass of hyperthermic water.

Localization of the zooxanthellae expulsion in the lower Keys is consistent with the hydrodynamics, geography, meterology, and thermodynamics of the region. Vaughan (1918) reported that summer (June-September) seawater temperatures were elevated at Sand Key compared to Dry Tortugas, Carysfort Light, or Fowey Rocks. The east-west axis of the lower Keys reef tract accommodates heating of the water column there; winds and seas during summer are normally from the ESE, a path parallel to the reef tract axis. In the upper Keys, the reef tract axis is N - S, hence winds and seas are orthogonal to the reefs, affording greater water exchange across the reefs.

Scleractinia accommodate poorly to slowly elevating seawater temperature (Mayer 1914). Mayer reported that A. palmata, A. muricata (=prolifera and/or cervicornis), Agaricia sp., M. annularis, M. cavernosa (listed as genus Orbicella), P. astreoides, D. clivosa, and S. siderea suffered physiological stresses between 31.8 and 36.4°C. Death occurred at temperatures exceeding 35.8°C (Mayer 1914). Maximum temperature reported from the lower Keys during August-September 1983 was 33°C. During low tides on calm days, temperatures may have exceeded 33°C. Natural localized hyperthermic conditions as high as 38°C have been reported from shallow Florida reef flats (Mayer 1914).

Shallow-water coral reef communities are polytrophic. Carbon photosynthetically fixed by zooxanthellae is translocated to animal tissues (Muscatine and Porter 1977). Reef cnidarians also obtain carbon heterotrophically from zooplankton, from feeding on other benthos, and from dissolved and particulate organics. In shallow water, the autotrophic energy source is a major contribution to resident cnidarian populations. Some coral species receive the majority of daily carbon requirements via phototrophism (Muscatine et al. 1981; Davies 1984; Porter 1984). Calcification, reproduction, and maintenance are affected when the carbon budget is radically changed. Expulsion of zooxanthellae alters the trophic balance, requiring affected organisms to rely to a greater extent on heterotrophic resources.

Expelled zooxanthellae can be consumed by filter-feeding organisms (Frankboner and Reid 1981). Recovery of zooxanthellae following an expulsion is reported to take 6-15 weeks (Goreau 1964; Jaap 1979), during which surviving S. microadriaticum undergo division to reestablish symbiont populations within host cnidarians. Additional zooxanthellae may be secondarily obtained via zooplankton prey (Fitt and Trench 1981; Fitt 1984) and from detrital material (Steele 1975). Connell (1973; 1978) proposed that disturbances of intermediate magnitude and frequency were responsible for maintaining high species diversity in shallow-water coral reef communities. In Florida, the shallow spur and groove habitat supports low diversity coral communities (Jaap 1983; 1984). Disturbance is of a magnitude and/or frequency that does not enhance high diversity. During the present event, overall species diversity decreased (although at least temporary increases were noted in a few quadrats). Dominance of the most abundant, and presumably most tolerant, organisms increased.

The source of alternative nutrition for affected cnidarians on the shallow reefs is unknown. Is there sufficient energy stored to compensate for zooxanthellae loss? Do degenerating zooxanthellae create an organic soup that can be utilized by the blanched cnidarians? Are physiological processes reduced or shut down to compensate for lost energy? Reef ecologists should focus attention on these questions to better understand the significance of zooxanthellae expulsions.

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PAST OCCURRENCES IN CARIBBEAN AREA

Senator WEICKER. Would both of you like to characterize it? Do we have a problem here? Is this something that you feel is unique in terms of your own experience and your own lives, or is it something that has occurred several times in other forms?

Dr. LANG. We know it has occurred several times in much smaller forms in the recent past in the Caribbean area. We know of no previous event which is as widespread as this current event is. We also know, in general, that the widespread bleaching event that occurred in the Eastern Pacific in the El Niño year, in many areas, corals, after they first showed signs of being affected, it was a period of several months or even 6 months before they subsequently died.

So even though at the moment, for the most part, we are reporting bleaching of corals, and we are not currently saying that we know that corals are dying as a result of this event, we can't, as yet, be sure whether they will ultimately recover or if they will die.

At the moment, in my opinion, we cannot answer the question of potentially how important is this event going to be in terms of the ecology of these reefs.

Mr. JAAP. I would echo what Judy has to say. This event, with the Diadema die-off and all the other things that are going on in the Caribbean, points out a need to improve our ability to investigate these events, communicate them so that scientists can have an opportunity to get in there at the first incidence and follow these things closer.

We have very poor ability, sometimes, to react to these things and get an investigative effort going due to the time lag between the first observation and the time when someone can really get going on it.

We had these small cases in the past which were minor events compared to the magnitude of this one. So this is of concern to us.

Dr. LANG. I would also like to add that I am personally concerned about the fact that to the best of our knowledge at the moment, the areas in which bleaching was first noted happen to be some of the presently most stressed coral reefs in the Caribbean Basin area, so it is one of many possibilities that they were responding earlier because they were already more stressed than the corals in places like Lee Stocking, which were relatively late to show this phenomenon.

But it is also conceivably possible that they responded first because they, whatever this perturbation is, was first experienced there, or the magnitude of the perturbation was greatest there.

ACTIONS REQUIRED TO RESOLVE PROBLEM

Senator WEICKER. What do you think the next logical step is insofar as getting on top of the problem?

Dr. LANG. I think we have to find out what is happening. I think at the moment, in part, we are hampered by not really being on top of the event as it is occurring now. We can't present a plausible explanation for what is responsible, in part, for lack of information at the moment.

Some of it is there; some of the marine labs around the Caribbean do occasionally or even regularly collect environmental data, and that needs to be collated to look for some associated physical factor. This has happened so fast that it seems most unlikely that it is a pathogen or a pollutant that has been released at some source in the Caribbean and which has spread to other areas. Water currents just wouldn't carry something that quickly.

Senator WEICKER. Have any of you been in communication with NOAA on your findings on these matters?

Mr. JAAP. In the Communications Office, I have had communications with Ralph Lopez—he is here today—and with people working for them down in the Keys area.

PAST DIADEMA KILL

Senator WEICKER. I was amazed when several years ago during the appropriations hearing, I raised the issue of the Diadema kill, and nobody knew anything about it. I was really very surprised that nobody even knew. They said, "Fine, we will get an answer for you, Senator," but nobody was at all familiar with what was going on then. That is why I wondered what the state of knowledge is now.

Dave is here, and I will ask him to clarify that.

DIADEMA PATHOGEN

Mr. JAAP. There is a paper that was published in the last year that describes the pathogen for the Diadema, and it was reported, I believe, Diadema is coming back in Florida in some spots. It is spotty.

Senator WEICKER. You have got to educate. When you say a pathogen?

Mr. JAAP. Disease organism that caused the death.

Senator WEICKER. You have identified that.

Mr. JAAP. There is a paper.

Senator WEICKER. That disease organism traveled throughout the entire area?

Mr. JAAP. The pattern of that event started down around Panama and worked its way slowly up the Caribbean coast and into Florida and down into the Greater and Lesser Antilles. It was a waterborne event.

This event occurred so rapidly and so in many places, that is why we suspect it is not disease oriented.

Senator WEICKER. That is interesting.

Mr. JAAP. That would follow it from island to island, and there would be weeks or months between the time it left Panama until it got to a particular point.

Senator WEICKER. Has that pretty much ended?

Mr. JAAP. The Diadema die-off?

Senator WEICKER. Yes.

Mr. JAAP. I believe so.

Dr. LANG. In several places, as populations started to recover, there did seem to be a mortality of urchins that was reminiscent of how they died during the epidemic.

Senator WEICKER. I suppose some of this might be because for the first time we have people looking at the marine ecosystems. Maybe what I am trying to say is that maybe these things have occurred for hundreds and hundreds of years, but nobody was down there plowing around. Admittedly, all of us in this room would agree that the effort really is minimal in terms of what our government does, but there is an effort between what the government does, what the universities do, and private foundations do, et cetera.

There are scientists there where there were none before. So to that extent, maybe, as I said, everything that is going on has happened in the past, but we just never knew about it.

Dr. LANG. Yes, Senator, but it is also true that there are artificial stresses on these corals which were not present in the past, which potentially make them far more vulnerable to these natural stresses when they occur in their regular periodic fashion.

Senator WEICKER. I agree with you on that. I think, as I recall, off the Island of St. Croix, that was a time there when you had a great deal of building on the island, a great deal of stuff washing off the island itself.

Dr. OGDEN. We haven't seen anything yet there, Senator. It is just starting.

Senator WEICKER. Am I correct when I say that created a problem for the coral?

Dr. OGDEN. Absolutely. Absolutely.

Senator WEICKER. Which was obviously a man-made crisis.

Dr. LANG. Worldwide, sediment influxes are recognized as one of the major perturbations on these communities.

Mr. JAAP. And marine operations, as well.

Dr. LANG. They are so closely correlated with agriculture or industrialization or just urbanization.

Senator WEICKER. I thank you very much for your testimony. Your full statements will be included in the record, and also any questions for response to the record will be appreciated.

Dave, you are here. I know you are not scheduled on the witness list. I wonder if you might present yourself here for a minute.

DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NATIONAL UNDERSEA RESEARCH PROGRAM

STATEMENT OF DAVID DUANE, ACTING DIRECTOR, NATIONAL UNDERSEAS RESEARCH PROGRAM, NOAA

INVOLVEMNET OF NOAA IN RESEARCH PROGRAM

Mr. KANE. If I could add, Senator, we will be mailing all the witnesses a copy of the transcript. We would like it returned as promptly as possible. There is a lot of technical information here. I am sure the reporter is having a time with it this morning. If you could return it to us so we can print it?

Senator WEICKER. Before we get to the last witness, why don't you identify yourself for the records.

Mr. DUANE. I am Dave Duane. I am Acting Director of the National Undersea Research Program.

Senator WEICKER. There seems to be a feeling that there should be some organized effort to look at this matter, and I think the feeling would clearly be that this would best fall under the aegis of NOAA? Do you think so? Is it something you are prepared to handle?

For one thing, I don't agree with Bob Dill. I don't think I need a committee to give a direction to NOAA. I think if there is a problem here, there is no reason why NOAA shouldn't dive into it. Whether it has the adequate funds to do that, whether there are others that would want to have input as far as personnel is concerned is another question. How do you view this thing? We have got to start some place.

Mr. DUANE. I think there are mechanisms available through NOAA's existing programs to address some of the issues that have been raised so far and, in fact, you may learn more about it during the testimony from Dr. Carpenter, the Science Director of our St. Croix program.

For example, with the new science program, utilizing the habitat, we do have some research which is looking at the coral community, the fine scale ecosystem and some of the similar biotics, the biology and the feeding habits of the coral.

So in some measure, we are looking at that element. We do, of course, have a number of other undersea research programs; the Caribbean Marine Science Center is looking at this. So in effect, we do have activity under way.

STUDIES CONDUCTED BY FISHERIES SERVICES

Senator WEICKER. Is there a specific study going on right now as far as the Jersey coast or the porpoise kill? Is there somebody handling something there? Is there anything specific there?

Mr. DUANE. I can't answer that for other elements of NOAA. I don't know if there is anything.

Ms. EILEEN SHEA. I know the National Marine Fisheries Service has been participating in what amounts to both an interstate and a Federal effort, so yes, there is some work on in the fisheries service.

Mr. TRUESDALE. Some of these things are being addressed in the status trends program.

Senator WEICKER. Beg your pardon?

Mr. TRUESDALE. Some of the oceanography issues are being addressed through the status program at NDS, and there have been several surveys.

UNITING OF INVESTIGATIVE PROGRAMS

Senator WEICKER. All right. I am still not convinced that we are handling this thing in the right way. Maybe these are all distinct and separate problems.

Let me just say one thing. I don't care whether you are the National Science Foundation or NURP or Marine Fisheries. I realize much of the world probably isn't interested in coral right now, but if we go through another exercise such as we went through this summer, I tell you, people are going to be yelling and screaming at all three agencies as to where the answer is to this?.

We are all among friends here in this room, and we better start to figure out what the plan of attack is going to be so that we can give an answer or at least say we are coordinated and we are working on it.

But if it comes out that we have got about 50 million disjointed efforts going on, people are doing something else here and something else there, you and NOAA and, as I say, the Science Foundation and Marine Fisheries are going to catch it. I can see it coming now.

DECEMBER MEETING SCHEDULED

Mr. DUANE. There is one other item I might bring to your attention, and that is that in early December, we, NURP, are scheduling a meeting with the Program Directors and the Science Directors of our Undersea Research Centers along with the directors of the various Caribbean labs, a meeting scheduled in St. Croix to begin to look at a number of science issues, and it seems to me quite logical that this is clearly——

Senator WEICKER. When is this meeting being held?

Mr. DUANE. It is tentatively scheduled now for Thursday, December.

Dr. OGDEN. Tenth, I believe, the 9th or the 10th.

Senator WEICKER. Is this around the time I was supposed to be down there?

Dr. OGDEN. Right.

Senator WEICKER. Let me keep on going in the hearing. I thank you very much.

Panel 3

NATIONAL SCIENCE FOUNDATION

DIVISION OF OCEAN SCIENCES

STATEMENT OF CHRISTOPHER F. D'ELIA, PH.D., PROGRAM DIRECTOR, BIOLOGICAL OCEANOGRAPHY PROGRAM, DIVISION OF OCEAN SCIENCES, NATIONAL SCIENCE FOUNDATION, WASHINGTON, DC

INTRODUCTION OF WITNESSES

Senator WEICKER. Our next set of witnesses are Dr. Christopher F. D'Elia, Program Director for the Biological Oceanography Program, Division of Ocean Sciences at the National Science Foundation; Dr. Robert C. Carpenter, Science Director at the National Undersea Research Program at Fairleigh Dickinson University; and Dr. John C. Ogden, Director of the West Indies Laboratory.

Gentlemen, it is nice to have you.

Dr. D'ELIA. I want to thank you for inviting me to testify today. My name is Christopher D'Elia. I am the Program Director of the Biological Oceanography Program Division of Ocean Sciences——

Senator WEICKER. I did not mean to mispronounce your name, but in my State there are very proud Italians, and they call themselves D'Elia, believe me. [Laughter.]

Dr. D'ELIA. If I can defend myself, Senator, I come from your State. [Laughter.]

I, too, am very proud of my Italian family.

Senator WEICKER. I did not mean to mispronounce.

Dr. D'ELIA. We are not the same people that have the automobile business who pronounce the name differently. [Laughter.]

Senator WEICKER. I just wanted to say it is a great name in our State.

Dr. D'ELIA. As I was saying, I am at the National Science Foundation.

I appreciate the opportunity to review for you some of the projects we now fund at NSF that relate directly or indirectly to coral bleaching.

REASONS FOR CORAL BLEACHING

As we have already heard, reef-building corals are animals that have what are known as a "mutualistic symbiosis" with minuscule plants called zooxanthellae. The zooxanthellae actually live inside the coral tissue and provide many benefits to their animal hosts, not the least of which is to enhance the rate at which the coral tissue makes its skeleton. Skeletal material, of course, as we have already heard, forms

the physical framework for reefs. I will just mention also that there are nutritional benefits that accrue to both symbionts in this case.

Since the zooxanthellae are brown, they provide a brownish coloration to their coral hosts, which would otherwise be white. When they are stressed by environmental conditions, they expel their zooxanthellae at high rates and take on a whitish coloration. This phenomenon is referred to as bleaching. The three most typical causes of the bleaching effect that bear on this are salinity, oxygen, and temperature stress.

Now, the massive extent of coral bleaching observed in the Caribbean, we think, is most likely due to temperature stress. Corals have been exposed to temperatures exceeding 30 to 31 degrees, or 87 degrees Fahrenheit, converting Celsius to Fahrenheit, and they often expel their zooxanthellae when prolonged exposure to such temperatures exist.

The corals may die after this occurs. Accordingly, the consequences of temperature stress can be very severe. Of course, if the stress is not long, it may not adversely affect them so severely.

Senator WEICKER. Just let me interpret. So, in other words, what I have seen here, what has been described to me, may not necessarily mean a killing of coral.

Dr. D'ELIA. That is correct; it may not. It depends on the duration.

Senator WEICKER. It may be just a discoloration.

Dr. D'ELIA. It depends on the length of the exposure.

Senator WEICKER. How do you know it is dead?

Dr. D'ELIA. We need to examine the tissue visually and, perhaps, histologically.

Senator WEICKER. We saw that cutaway of that microscopic slide there. What do you think I was seeing? Were they both alive?

Dr. D'ELIA. One of the zooxanthellae was clearly dead—that which was being shown on the left side. The total cellular structure was destroyed, and it was gone.

Senator WEICKER. That was destroyed. As I said before, I need to get educated on these matters, and I think the average person would deduce that bleaching meant the killing of coral. I just want to make that point clear that it is not necessarily so.

Dr. D'ELIA. Not necessarily, but it often leads to the killing of coral, and susceptibility to diseases which can kill corals.

SEA-SURFACE TEMPERATURES

Unusually high sea-surface temperatures were recorded in the Caribbean, as we heard, but the cause and geographic extent of these temperatures are really uncertain.

The high sea-surface temperatures are likely to relate to large-scale weather perturbations that occur on a 3- to 5-year time scale. They may also relate to longer term global climate change that may exacerbate thermal stress due to such perturbations. We cannot determine the cause at present because the historical climate record for the Caribbean and Western Atlantic has not been examined in detail.

However, relevant research programs at the National Science Foundation are in progress on large-scale weather events and their consequences in other regions. An example of such a large-scale weather perturbation is the so-called El Niño/Southern Oscillation Phenomenon [ENSO], which is known to affect coral reefs in the eastern Pacific Ocean over time scales of several years.

The Global Geosciences Program at NSF, in collaboration with the National Oceanographic and Atmospheric Administration and other Federal agencies, funds important interdisciplinary research into the physical oceanographic and meteorological causes of ENSO.

The so-called tropical ocean-global atmosphere experiment, called TOGA, specifically addresses this topic. The Foundation's Biological Oceanography Program supports research on the biological consequences of ENSO and also comparable events.

One NSF project which is very relevant to the present issue is that of Dr. Peter Glynn of the University of Miami. Dr. Glynn has found evidence of substantial coral bleaching and mortality in eastern Pacific corals across the Isthmus of Panama. That mortality is associated with the particularly strong ENSO effect of 1982–83 that produced very high sea-surface temperatures comparable to those observed in the Caribbean last summer.

Dr. Glynn is presently leading an international team of scientists that studies ENSO perturbations on eastern Pacific reefs and the rate at which the reefs recover, if at all, from such perturbations.

The Foundation also supports the research of other scientists, such as Dr. R.T. Barber of the Monterey Bay Aquarium Research Institute. Dr. Barber studies the impact of ENSO events on plant productivity in ocean waters off Peru and elsewhere.

Also, Dr. Paul Dayton of the Scripps Institution of Oceanography, who has been investigating ENSO-related effects on California kelp communities, is supported by the Foundation.

While the Foundation supports substantial work on many aspects of coral reef ecology in the Caribbean, and, I might add, to critical investigations going on right now, to my knowledge, no one has proposed yet to study coral bleaching and its relationship to sea-surface temperatures in the Caribbean.

I must say that we are a responsive agency in the sense that we deal with proposals coming into us. We don't necessarily solicit studies. We are more likely to respond to proposals and to studies than to actually ask for them. With that, I will be pleased to answer any questions you have.

Senator WEICKER. Why don't I wait and we will proceed with the panel. Dr. Carpenter.

[The prepared statement of Dr. Christopher F. D'Elia follows:]

PREPARED STATEMENT OF DR. CHRISTOPHER F. D'ELIA

PROGRAM DIRECTOR
BIOLOGICAL OCEANOGRAPHY PROGRAM
DIVISION OF OCEAN SCIENCES
DIRECTORATE FOR GEOSCIENCES
NATIONAL SCIENCE FOUNDATION

Thank you for inviting me to testify before this Subcommittee today. My name is Christopher F. D'Elia and I am Program Director of the Biological Oceanography Program, Division of Ocean Sciences, at the National Science Foundation.

I appreciate the opportunity to review for you some of the projects we now fund at NSF that relate directly or indirectly to coral bleaching.

Reef-building corals are animals that have what is known as a "mutualistic symbiosis" with miniscule plants called zooxanthellae. The zooxanthellae actually live inside the coral tissue and provide many benefits to their animal hosts, not the least of which is to enhance the rate at which the coral tissue makes its skeleton. Skeletal material forms the physical framework for reefs.

Since the zooxanthellae are brown, they provide a brownish coloration to their coral hosts, which would otherwise be white. When corals are stressed by environmental conditions, they expel their zooxanthellae at high rates and take on such a whitish coloration--a phenomenon we refer to as "bleaching." Salinity, oxygen and temperature stress are the most common causes of bleaching.

The massive extent of coral bleaching observed in the Caribbean, we think, is due to temperature stress. Corals exposed to temperatures exceeding 30-31^{o}C (~87^{o}F) often expel their zooxanthellae. The corals may die after this occurs, accordingly, the consequences of temperature stress to coral reef ecosystems can be severe.

Unusually high sea-surface temperatures were recorded in the Caribbean last summer. The cause and geographical extent are uncertain, but the high sea-surface temperatures are likely to relate to large-scale weather perturbations that occur on a 3 to 5 year timescale. They may also relate to longer-term, global climate change. We cannot determine the cause at present, because the historical climate record for the Caribbean and western Atlantic has not been studied in detail.

However, relevant research programs at NSF are in progress on large-scale weather events and their consequences in other regions. An example of a large-scale weather perturbation is the so-called El Niño/Southern Oscillation (ENSO) phenomenon, which is known to affect coral reefs in the eastern Pacific Ocean over time scales of several years.

The Global Geosciences Program of NSF, in collaboration with the National Oceanographic and Atmospheric Administration (NOAA) and other Federal agencies, funds important interdisciplinary research into the physical oceanographic and meteorological causes of ENSO. The Tropical Ocean-Global Atmosphere Experiment (TOGA) specifically addresses this topic. The Foundation's Biological Oceanography Program supports research on the biological consequences of ENSO and comparable events.

One NSF project which is relevant to biological consequences of ENSO on coral reefs is that of Dr. Peter Glynn of the University of Miami. Dr. Glynn has found evidence of substantial coral bleaching and mortality in eastern Pacific corals that is associated with the particularly strong ENSO event of 1982-1983 that produced high sea-surface temperatures comparable to those observed in the Caribbean last summer. Dr. Glynn is leading an international team of scientists that studies ENSO perturbations on eastern Pacific reefs and the rate at which the reefs recover from such perturbations.

NSF also supports the research of other scientists such as Dr. R.T. Barber of the Monterey Bay Aquarium Research Institute. Dr. Barber ~~who~~ studies the impact of ENSO events on plant productivity in ocean waters off Peru and elsewhere. Also, Dr. Paul Dayton of Scripps Institution of Oceanography, who is investigating ENSO-related effects on California kelp communities, is supported by the Foundation.

While NSF supports substantial work on many aspects of coral reef ecology in the Caribbean, to my knowledge, no one has proposed yet to study coral bleaching and its relationship to sea-surface temperatures in the Caribbean.

I will be pleased to answer your questions about these and related NSF-supported projects.

NONDEPARTMENTAL WITNESSES

NATIONAL UNDERSEA RESEARCH PROGRAM

STATEMENT OF DR. ROBERT C. CARPENTER, PH.D., SCIENCE DIRECTOR, NATIONAL UNDERSEA RESEARCH PROGRAM, FAIRLEIGH DICKINSON UNIVERSITY, WEST INDIES LABORATORY, TEAGUE BAY, CHRISTIANSTED, ST. CROIX, U.S. VIRGIN ISLANDS

CHANGE IN COASTAL ECOSYSTEMS OF CARIBBEAN

Dr. CARPENTER. Senator Weicker, thank you for this opportunity to testify before the subcommittee this morning. As we have heard earlier this morning, coastal ecosystems of the Caribbean are changing. Many of these changes may be related to human-induced disturbance. Stresses caused by coastal development such as increased erosion and freshwater runoff threaten to eliminate or permanently change these ecosystems in many areas of the region.

Increased human populations are also resulting in overexploitation of the as yet poorly understood marine resources of shallow coastal environments. A major challenge is to preserve and protect these resources until a suitable body of knowledge exists to ensure their proper management.

Natural disturbances can provide the opportunity to evaluate and study the inner workings of complex biological and physical systems. Knowledge gained from the study of these natural events can assist scientists in their ability to predict changes in an ecosystem that will result from an anticipated disturbance, such as increasing coastal development.

During the past 10 years, there have been several large-scale "natural" disturbances to Caribbean coastal ecosystems. In 1977, large stands of elkhorn coral began to die in areas throughout the region. This continued to occur until the majority of the colonies of this species were killed. This coral is one of the major reef-building corals throughout the Caribbean. The cause of this "disease" is unknown; it may have been a natural recurring phenomenon that occurs when the population density of this species attains a certain level.

Other scientists believe it may have been stress related. Unfortunately, there were no short-term studies of the causative agent of this species-specific mortality, and there have been no long-term studies of the effects of this natural disturbance on Caribbean coral reefs.

ELKHORN CORAL

Senator WEICKER. Let me just stop you one second there so I don't forget. I have seen lots of dead elkhorn coral. Are there populations of live elkhorn coral, and is it expanding? What is happening?

Dr. CARPENTER. We have gone through a period of what was called a white band disease; we do not know what the causative agent is. It resulted in the die-off of many of the colonies of this one species, and now we are seeing recruits, young colonies, young individuals of that coral now settling on the reef and growing up.

It wasn't eliminated but in any sense of the word. However, the density of it was cut way back.

Another "natural" disturbance that occurred in the western Caribbean in 1983 was the localized bleaching of reef corals, most likely in response to elevated sea-surface temperatures. Temperatures as high as 32 degrees Celsius were recorded off the coast of Panama. Temperatures above 30 degrees Celsius, as we have heard, are generally believed to be stressful for reef corals. Whether these elevated temperatures are the result of abnormal climatic conditions, altered patterns in the physical oceanography of the region (current patterns) or some combination of these or other patterns is unclear.

LONG-SPINED BLACK SEA URCHIN

Perhaps the most dramatic "natural" event to occur in the Caribbean was the mass mortality of one of the most abundant sea urchin species on coral reefs, the long-spined, black sea urchin. This sea urchin was one of the most important plant-eating organisms that inhabited many regions of the Caribbean.

The signs of the mass mortality were first noted outside the entrance to the Panama Canal near Galeta in Panama. Eventually, the mass mortality event reached the Florida Keys, Bermuda, and, to our knowledge, all the major islands in Greater or Lesser Antilles chains in the Caribbean.

Where previous data on population sizes of Diadema exist, it appears that 95 to 99 percent of the sea urchins of this one species succumbed to this mass mortality. No other organisms, including species of related sea urchins, were affected by this event.

The effects of this mass mortality were dramatic. The abundance of algae on coral reefs has increased greatly, and in some cases, has overgrown and killed corals. Prior to the mass mortality of Diadema, herbivorous fishes, like parrotfishes and surgeonfishes competed with the sea urchins for algae as food.

Following the removal of nearly all of these sea urchins, increased feeding by fishes was observed, and eventually, 2 years after the die-off, the population sizes of some of these plant-eating fishes was greater than before the die-off.

However, even with the increased abundance of these plant-eating fishes, they were not able to keep up with the rapidly glowing algae, and many coral reefs remain dominated by large stands of algae.

I might add at this point that much of this work was supported by the University of Puerto Rico Sea Grant program.

What caused the mass mortality of Diadema remains somewhat unclear. As Walter Jaap has told us this morning, there has been a bacterium that was isolated that is pathogenic or will kill Diadema. However, this is only circumstantial evidence that that was the actual cause.

SEA-SURFACE TEMPERATURES

One possible explanation is that higher sea-surface temperatures resulted in a population outbreak of some organism, such as a protozoan, a bacterium or a virus that normally is in sea urchin tissues but is kept in check at normal seawater temperatures. Such a mechanism explains the yearly die-off of sea urchins in some sub-arctic areas, such as Nova Scotia.

Although sea-surface temperatures were elevated in the western Caribbean during the time of the mass mortality, water temperatures were not measurably higher at other sites throughout the western Atlantic.

SHIP DISCHARGES

Another potential explanation for this mortality is that a ship transiting the Panama Canal from the Pacific to the Caribbean discharged ballast water containing, again, an orgamism that was able to infest Diadema and result in the observed symptoms and mortality. Whatever the cause, the effects on coral reefs of the Caribbean have been substantial.

The latest disturbance to Caribbean coral reefs is an unexplained bleaching of reef corals and other organisms throughout the region. This reportedly began, as we have heard, in September 1987 and is continuing to occur in many reef areas. Although sea-surface temperatures were near their maximum when the bleaching was first recorded, there are no obvious patterns in the distribution of bleaching and the available records of water temperatures in the area.

It is also unclear whether the corals that are bleaching, again, because of the expulsion of the symbiotic unicellular algae in their tissues, whether these corals are also dying.

CARIBBEAN MARINE ORGANISMS UNDER STRESS

One theme that runs through this list of "natural" disturbances is the idea that marine organisms in the Caribbean are under stress. As Dr. Lang has already mentioned, this stress may take the form of increased water temperature, which can have either direct effects, as hypothesized for the coral bleaching events, or indirect effects, as proposed as one explanation for the Diadema die-off.

Whether Caribbean ecosystems are stressed by human influences or whether seasonal patterns of water temperature, salinity and/or surface water currents result in cyclical stressing of these tropical ecosystems requires further study.

The problems in attempting to understand the events outlined above are two-fold. One problem is that we do not know the long-term patterns of the oceanography in the region and therefore, cannot determine the cause or causes of these phenomena; whether they are responses to "natural" events that operate on long time scales or responses to human-induced disturbances is rather unclear.

The second problem is that once these events are observed, there is no short-term mechanism to fund scientists to address the extent of the phenomena or their immediate effects.

RECOMMENDATION TO ADDRESS PROBLEMS

I would make two recommendations to address these problems. First, establish an integrated, Caribbean-wide monitoring effort that can create a data base of baseline environmental information. This includes such basic measures as water temperature, salinity, turbidity, tidal height, nutrient concentrations and meso- and microscale, (medium- and small-scale), current patterns.

Second, make funds available to Federal agencies that fund research in marine sciences in the Caribbean, which includes NOAA National Underseas Research Program; NOAA Sea Grant; and the National Science Foundation, and have these monies specifically designated to support studies of short-term phenomena.

NOAA's National Underwater Research Program at Fairleigh Dickinson University, located at the West Indies Laboratory in St. Croix, implements and coordinates a Caribbean-wide science program that provides scientists with the modern tools in oceanography to conduct marine research in the Caribbean region.

MONITORING PROGRAMS

In response to the need for a baseline of environmental data, we have also established a monitoring program that will gather basic oceanographic data from a limited number of sites. Although this is a beginning, to adequately address the problems discussed above, a Caribbean-wide integrated approach is required and could easily tie in with efforts being made to address patterns of environmental changes on a global scale. Organizing and funding such an effort should be a high priority.

NURP–FDU can contribute to the support of a study of short-term phenomena if funds are made available for such activities. The normal proposal merit review process ensures that the quality of the research support is high and maintains the integrity of the system. Our proposal process at present takes approximately six to seven months from proposal submission to actual beginning of the research.

The challenge is to maintain the integrity of the review process and the quality of the projects funded while cutting the time required for evaluation in order to allow study of events that are unanticipated and of short duration. Proposals requesting support for such an event could be evaluated by outside experts expeditiously using electronic mail, and phone reviews and funding decisions could be made at the program-

matic level. With the appropriate funding, NURP–FDU is capable of responding to these needs.

The marine resources found in the Caribbean region are of importance to the United States as well as to Caribbean nations. However, the ecosystems occupying the shallow marine environments which provide the majority of these resources are fragile, complex and poorly understood.

To ensure the proper protection and management of these resources, it is incumbent upon us to understand both the short- and long-term patterns of change that occur in the region and the ramifications for the health not only of the Caribbean marine environment, but also for the health and welfare of the people who depends on the resources that this marine environment provides.

Thank you.

Senator WEICKER. Thank you very much.

[The prepared statement of Dr. Robert C. Carpenter follows:]

MARINE ECOLOGICAL DISTURBANCES IN THE CARIBBEAN: A REVIEW WITH RECOMMENDATIONS FOR FEDERAL PROGRAMMATIC RESPONSES

Submitted by:

Dr. Robert C. Carpenter, Science Director
NOAA's National Undersea Research Program at
Fairleigh Dickinson University
West Indies Laboratory
Teague Bay, Christiansted
St. Croix, U.S. Virgin Islands 00820

I. INTRODUCTION

The rational utilization and management of coastal zone habitats and marine resources is a major challenge to modern, high energy consuming societies. Conflicting uses, over-exploitation of resources, and partial or total destruction of habitats, are urgent problems that confront managers and decisions makers. The solution to these problems are confounded by a lack of information about how different coastal marine ecosystems function, what interactions exist between different ecosystems, and how resistant individual and connected ecosystems are to perturbations.

During the next decade, it is likely that the Caribbean region will continue to undergo significant changes. Human population size in the region is expected to increase by 50% , while regional food and fish production has probably reached its maximum level or is already over-exploited. Given the limitations in the application of technology in many areas of the region, the Caribbean will continue to have an overall deficiency in food supply. In addition, increased urbanization and associated pollution will likely reduce the overall quality of life in the region.

The dominant ecosystems in Caribbean coastal areas are mangrove forests, seagrass beds, and coral reefs. Generally, these ecosystems are among the most productive in the world in spite of the basic nutrient limitations of tropical seas. Since the productivity of these ecosystems is the basis of the potential yield of shallow-water, living marine resources in the Caribbean region, a major goal is to determine the factors most responsible

for causing the demonstrated variability in organic productivity both within and between ecosystem types.

An increasing number of Caribbean coastal ecosystems are already experiencing environmental stress. Mangroves are being cut down for lumber and agricultural/urban development, deforestation of hillsides and wetlands is causing sediment stress on reefs due to erosion of denuded land, and coastal fish stocks are becoming overfished. Governments throughout the region are aware of the need for conservation and restoration, but one of the limitations is a sufficient understanding of how the coastal ecosystems work in order to develop sound management strategies. One of the goals of the National Undersea Research Program at Fairleigh Dickinson University (NURP-FDU) is to further understanding of the coastal ecosystems in the Caribbean. Elucidating and quantifying the processes that structure these complex tropical ecosystems will result in a better understanding of processes occuring in all marine ecosystems. Given the high degree of interconnection between global oceanic, atmospheric, and terrestrial processes, a Caribbean-wide science program could also contribute to a database for the construction of a Caribbean model for global changes in the biosphere.

II. A CARIBBEAN-WIDE NATIONAL UNDERSEA RESEARCH PROGRAM

A. General

Special justification for Caribbean research lies in recognition of the Caribbean as a crucial geopolitical center, possessing great natural resources and a relatively benign marine environment close to the United States mainland. The Caribbean, while geographically small, contains over 20, mostly developing nations with a disproportionate dependence on marine resources. There is little doubt as to the key position the Caribbean holds in United States national interests. For example, one sixth of the world's oil production passes through the Caribbean.

Despite their importance, relatively little is known about Caribbean marine environments, particularly in comparision to temperate marine environments. This condition reflects, in part, the geographical concentration of marine scientists in North

America, Europe, and Japan, and the lack of suitable laboratory and field facilities in many areas of the Caribbean.

As a result of the Reagan Administration's Caribbean Basin Initiative (CBI), the following needs in science and technology were identified: basic marine science studies, coastal marine resource development, and marine planning. It was recommended that the United States should seek to provide assistance through making available scientific expertise, creating data retrieval systems, and providing for research personnel exchanges. The Department of Commerce has been charged by the Administration to implement this program. More recently, a published report by NOAA and the Department of State's Agency for International Development (AID) ("Caribbean Marine Resources, Opportunites for Economic Development and Management", 1987) has identified several areas of need in the Caribbean. Primary among these are an increased understanding of the functioning of coastal marine ecosystems, increased transfer of knowledge and technology from developed to developing nations in the region, and increased collaboration between agencies in meeting the mangement and marine resource development goals. By utilizing the science program and the scientific expertise of NURP-FDU, NOAA is providing the Departments of Commerce and State with the means to meet some of the major goals and recommendations outlined in the NOAA/AID study.

B. Coastal Ecosystems

An important and unique ecosystem of the tropics is the coral reef. Coral reefs hold the greatest diversity of organisms of any marine ecosystem, providing a genetic storehouse for the needs of future generations. Caribbean reef biota are classified among the world's most productive ecosystems, ranking with intensively cultivated crops, such as corn and sugar cane. Coral reefs provide protection to coastlines and harbors from storms, are a major source of construction aggregate and sand, and also provide a basis for an increasingly valuable tourist industry.

Results generated by Caribbean research are applicable not only to tropical areas throughout the world, but also increase our understanding of basic ecological processes relevant to temperate regions. Coral reefs are the most complex ecosystems on earth, with the exception of tropical rain forests. Ecological interactions that are absent or only weakly expressed in temperate marine systems reach their highest development in coral reefs.

Understanding such complex systems will provide a data base from which a coherent and responsible plan can be formulated for the management of these valuable resources. Such understanding can be best accomplished through a long-term integrated program of scientific research.

III. CHANGES IN CARIBBEAN COASTAL ECOSYSTEMS

The coastal ecosystems of the Caribbean are changing. Many of these changes are likely related to human-induced disturbances. Stresses caused by coastal development, such as increased erosion and freshwater run-off, threaten to eliminate or permanently change these ecosystems in many areas of the region. Increased human populations also are resulting in over-exploitation of the, as yet, poorly understood marine resources of shallow coastal environments. A major challenge is to preserve and protect these resources until a suitable body of knowledge exists to ensure their proper management.

Natural disturbances can provide the opportunity to evaluate and study the inner workings of complex biological and physical systems. Knowledge gained from the study of these natural events can assist scientists in their ability to predict changes in an ecosystem that will result from an anticipated disturbance (such as increased freshwater run-off from coastal development).

During the past ten years, there have been several large scale "natural" disturbances to Caribbean coastal ecosystems. In 1977, large stands of elkhorn coral (*Acropora palmata*) began to die in areas throughout the region. This continued to occur until the majority of the colonies of this species were killed. This coral is the major reef-building coral throughout the Caribbean. The cause of this "disease" is unknown; it may have been a natural recurring phenomenon that occurs when the population density of this species attains a certain level. Other scientists believe it may have been stress-related. If corals are subject to sub-optimal conditions, such as increased water temperature, increased water turbidity, or changes in water salinity, they may be more susceptible to water pathogens to which they would normally be immune. Whatever the cause, the effects of this mortality have been dramatic in the amount of cover of living coral on many Caribbean reefs. This may have had important repercussions throughout the reef food web, as the relationships between

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organisms in such complex ecosystems as coral reefs, tend to echo the effects at one level, throughout the ecosystem. Unfortunately, there were no short-term studies of the causative agent of this species-specific mortality and there have been no long-term studies of the effects of this natural disturbance on Caribbean coral reefs.

Another "natural" disturbance that occurred in the western Caribbean in 1983, was the localized bleaching of reef corals, most likely in response to elevated sea surface temperatures. Temperatures as high as 32 °C were recorded off the coast of Panama; temperatures above 30 °C are generally believed to be stressful for reef corals. Whether the elevated temperatures were the result of abnormal climatic conditions, altered patterns in the physical oceanography of the region (current patterns), or some combination of these, is unclear.

Perhaps the most dramatic "natural" event to occur in the Caribbean, was the mass mortality of one of the most abundant sea urchin species on coral reefs, the long-spined, black sea urchin (*Diadema antillarum*). This sea urchin was one of the most important herbivores (organisms that eat plants) that inhabited coral reefs. The signs of the mass mortality were first noted just outside the entrance to the Panama Canal near Galeta. The symptoms began with the sloughing off of the epidermis of the spines and test (body), the spines drooped and finally fell out, and sea urchins either died in place or were consumed by fish predators. After appearing initially in Panama, the mass mortality moved eastward along the northern coast of Columbia, and northward along the coast of Central America. Eventually the mass mortality event reached the Florida Keys, Bermuda, and to our knowledge, all the major islands in the Greater and Lesser Antilles chains in the Caribbean. Where previous data on population sizes of *Diadema* exist, it appears that 95-99% of the sea urchins of this one species succumbed during this mass mortality. No other organisms, including other species of sea urchins, were affected by this event.

The effects of the mass mortality have been dramatic. The abundance of algae on coral reefs has increased greatly and in some cases has overgrown and killed corals. This may have the long-term effect of reducing the spatial complexity on these reefs as the dead coral skeletons are broken down over time by wave action and are not replaced by actively growing corals. This lack of spatial complexity can also affect other organisms which require the cracks and crevices provided by coral skeletons to hide from predators. Prior to

the mass mortality of *Diadema*, herbivorous fishes, like parrotfishes and surgeonfishes, competed with the sea urchins for algae to eat. Following the removal of nearly all these sea urchins, increased feeding by fishes was observed, and eventually, two years after the die-off, the population sizes of herbivorous fishes were greater than before the die-off. Even with the increased abundance of plant eating fishes, however, they are not able to keep up with the rapidly growing algae, and many coral reefs remain dominated by large stands of algae.

What caused the mass mortality of *Diadema* remains unclear. One possible explanation is that higher sea surface temperatures resulted in a population outbreak of a protozoan, bacterium, or virus that normally is present within sea urchin tissues, but is normally kept in check at normal seawater temperatures. Such a mechanism explains the yearly die-off of sea urchins in some sub-arctic areas. Although sea surface temperatures were elevated in the western Caribbean during the time of the mass mortality, water temperatures were not measurably higher at other sites throughout the western Atlantic. Another potential explanation for the mortality is that a ship transiting the Panama Canal from the Pacific to the Caribbean, discharged ballast water containing an organism (protozoan, bacterium, or virus) that was able to infest *Diadema* and result in the observed symptoms and mortality. The highly specific nature of the "disease" (it only affected *Diadema*) and the manner in which it moved around the western Atlantic and followed the surface water currents, support this hypothesis. Whatever the cause, the effects on coral reefs of the Caribbean have been substantial.

The latest disturbance to Caribbean coral reefs is an unexplained bleaching of reef corals throughout the region. This reportedly began in September 1987, and is continuing to occur in several reef areas. Although sea surface temperatures were near their maximum when the bleaching was first reported, there are no obvious patterns in the distribution of the bleaching and the available records of water temperature. It is also unclear whether the corals that are bleaching (which results from the expulsion of their symbiotic unicellular algae) are also dying.

One theme that runs through this list of "natural" disturbances, is the idea that marine organisms in the Caribbean are under stress. This stress may take the form of increased water temperature, which can have either direct effects, as hypothesized for the

coral bleaching, or indirect effects, as proposed for the *Diadema* die-off. Whether Caribbean ecosystems are stressed due to human influences, or whether seasonal patterns in water temperature, salinity, and/or surface water currents result in cyclical stressing of these tropical ecosystems, requires further study.

IV. PROGRAMMATIC RESPONSES TO SHORT-TERM ECOLOGICAL EVENTS

The problems in attempting to understand the events outlined above are two-fold. One problem is that we do not know the long-term patterns in the oceanography of the region and therefore cannot determine the cause(s) of these phenomena; whether they are responses to "natural" events that operate on long time scales, or responses to human-induced disturbances, is unclear. The second problem is that once these events are observed, there is no short-term mechanism to fund scientists to address the extent of the phenomena or their immediate effects. I would make two recommendations to address these problems:

1) Establish an integrated, Caribbean-wide monitoring effort that can create a database of baseline environmental information.This includes such basic measures as water temperature, salinity, turbidity, tidal height, nutrient concentrations, and meso- and microscale current patterns.
2) Make funds available to federal agencies that fund research in marine sciences in the Caribbean (NOAA National Undersea Research Program, NOAA Sea Grant, and the National Science Foundation), specifically designated to support studies of short-term phenomena.

NOAA's National Undersea Research Program at Fairleigh Dickinson University (NURP-FDU) in St. Croix, U.S. Virgin Islands, implements and coordinates a Caribbean-wide science program that provides scientists with the modern tools of oceanography to conduct marine research in the Caribbean region. In response to the need for a baseline of environmental data, we have also established a monitoring program that will gather basic oceanographic data from a limited number of sites. Although this is a beginning, to

adequately address the problems discussed above, a Caribbean-wide, integrated approach is required and could easily tie in with efforts being made to address patterns of environmental changes on a global scale. Organizing and funding such an effort should be a high priority.

NURP-FDU can contribute to the support of the study of short-term phenomena if funds are made available for such activities. The normal proposal merit review process ensures that the quality of the research is high and maintains the integrity of the system. Proposals to NURP-FDU are sent out for five mail reviews from outside experts in the appropriate areas of interest. The proposals and mail reviews are then presented to a peer review panel which makes funding recommendations to the program. The time from proposal submission to funding is normally six to seven months. The challenge is to maintain the integrity of the review process and the quality of the projects funded, while cutting the time required for evaluation, in order to allow study of events that are unanticipated and of short duration. Proposals requesting support for such an event could be evaluated by outside experts expeditiously using electronic mail and phone reviews and funding decisions could be made at the program level. With the appropriate funding, NURP-FDU is capable of responding to these needs.

The marine resources found in the Caribbean region are of importance to the United States as well as to Caribbean nations. However, the ecosystems occupying the shallow marine environments which provide the majority of these resources, are fragile, complex and poorly understood. To ensure the proper protection and mangement of these resources, it is incumbent upon us to understand both the short and long-term patterns of change that occur in the region, and their ramifications for the health of not only the Caribbean marine environment, but also for the health and welfare of the people that depend on the resources this marine environment provides.

WEST INDIES LABORATORY, TEAGUE BAY

CHRISTIANSTED, ST. CROIX, U.S. VIRGIN ISLANDS

STATEMENT OF JOHN C. OGDEN, PH.D., DIRECTOR, WEST INDIES LABORATORY, TEAGUE BAY, CHRISTIANSTED, ST. CROIX, U.S. VIRGIN ISLANDS

DIVERSITY OF CARIBBEAN SEA

Senator WEICKER. John.

Dr. OGDEN. Senator Weicker and other members of the subcommittee, as a 20-year resident of the Caribbean and as director of the West Indies Laboratory, I am very grateful for the opportunity to come before you to discuss, in the broader context of the Caribbean Basin, the dramatic events which have been described by my colleagues.

The Caribbean Sea is a microcosm which contains many of the political, economic and environmental problems of the tropical coastal seas of the world. It is bounded by more than 21 nations and numerous dependencies of Central and South America and of the Greater and Lesser Antilles.

The Caribbean offers marine scientists a challenge, an opportunity and even an obligation for cooperative international marine research and resource management.

I have one slide, Senator, that I would like to put up.

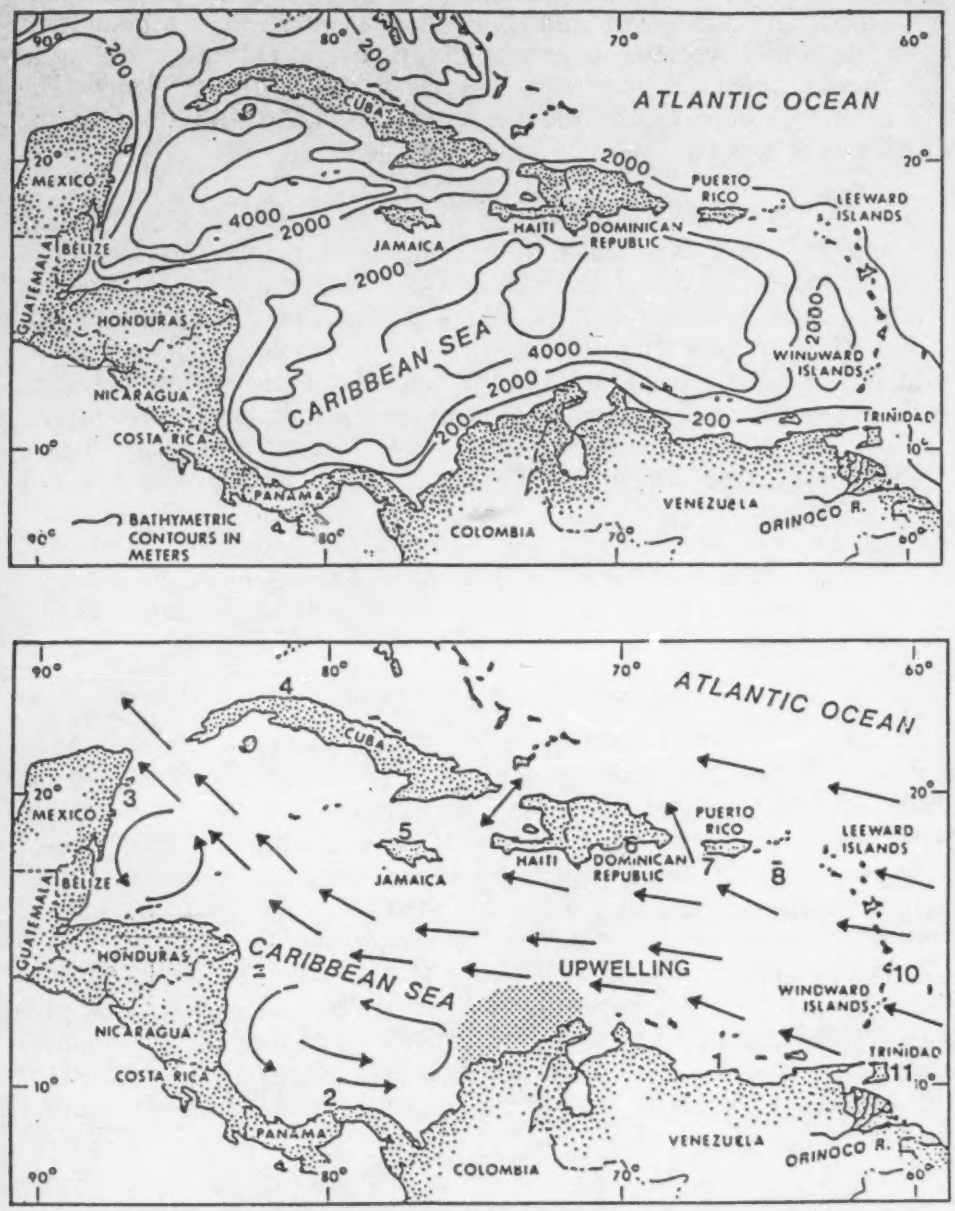

FIGURE 1: Maps of the Caribbean Sea showing bathymetric contours (top) and current patterns (bottom). The numbers (bottom) refer to the tentative CARICOMP research sites.

CARIBBEAN CURRENT CIRCULATION PATTERNS

This figure, which shows the Caribbean current circulation patterns tells a story. The Caribbean is a unified sea. The agent of that unification is, as Dr. Dill mentioned, the Caribbean current sweeping out of the central Atlantic from Africa and connecting with the Caribbean current.

The Caribbean is small, relatively speaking, and is completely interconnected. The plants and animals of the Caribbean have a planktonic larval stage of 2 weeks to a year in duration. The currents traveling at the speeds noted on the map will carry these larvae widely. The homogeneity, therefore, of the plant and animal distributions of the Caribbean is striking.

MARINE LABORATORIES IN CARIBBEAN BASIN

There are more than 17 marine laboratories within the Caribbean Basin bounded by Central America and the Greater and Lesser Antilles. Many of these laboratories have a long tradition of sharing of research results. The Association of Island Marine Laboratories, for example, with 23 members, including Florida and Bermuda, was founded in 1957. However, studies done at marine laboratories tend to be undertaken in isolation over short periods of time. Comparison between sites is difficult because the studies have differing objectives and use different methods.

Thus, generalizations which we develop at one site may not be valid at other sites. Senator, I believe that this bleaching event provides us the opportunity to get our act together, particularly on the methods that we use to approach this study of coral reefs.

ECOLOGICAL RESEARCH PROGRAM

At several workshop meetings of Caribbean marine scientists held at the West Indies laboratory of Fairleigh Dickinson University in St. Croix and the Discovery Bay Marine Laboratory of the University of West Indies in Jamaica in 1982 and 1985, a program of sustained ecological research was designed involving a cooperative network of all Caribbean marine laboratories, and I underline the "all" part of that, because there are numerous national representatives.

This program, now in the planning stage, established research sites and a manual of standardized methods to collect monitoring data. This data will be centrally processed and will be incorporated into regional models which will help explain not only phenomena such as the coral bleaching event, but will provide the basis for rational regional resource management.

SEA TEMPERATURES

We have heard in the hearing this morning, Senator, that temperature is a likely implicated in the bleaching event. It strikes me that temperature is the single simplest and most obvious parameter that one would want to measure in the sea. In fact, I can tell you that temperature is not being measured in a regionally coordinated manner. That, to me, says more than anything of the need for a regional network approach.

Central to the network is the training of Caribbean marine scientists and technicians in the application of the techniques that we in the United States have developed so superbly, including satellite technology, submersibles, remote operating vehicles, and, of course, the latest

diving technology exemplified by NOAA's new underwater laboratory, Aquarius, which will be mobile in the Caribbean.

The network of laboratories will make the best information available at the time of crisis events such as coral bleaching, while stimulating, over the long term, basic research leading to explanations of cause and effect.

WHITE BAND DISEASE

Dr. Carpenter mentioned white band disease (WBD). WBD has killed 80 to 90 percent of the Acropora palmata, elkhorn coral, at the Buck Island Reef National Monument managed by the National Park Service in St. Croix.

As he mentioned, we do not know the cause of this disease. We do not know, because we don't have a network in place, whether or not this disease, which has proven to be devastating to this species in St. Croix, is spreading through the region.

This is a failure on the part of marine laboratories to get their act together, but I don't think they can be solely held to blame because attempts to provide funding for such a network have met with some resistance.

The Caribbean governments are aware of the lack of information on marine resources but until now, have not pooled their respective knowledge and addressed problems on a regional basis.

Through the recent planning efforts of NOAA, including the Office of Undersea Research, the Sea Grant program, U.S. AID, the National Science Foundation and others, we are becoming aware of the regionality of the Caribbean, its interconnectedness and the necessity to manage its resources as a unit.

U.N. EFFORTS IN AREA

UNESCO and the Intergovernmental Oceanographic Commission of the United Nations have been, in my opinion, particularly effective in providing the political groundwork which will lead to international scientific cooperation.

The Caribbean lies on our back doorstep, yet has been too easily ignored. Other countries in the region have eclipsed the United States in support of marine resources research and development as well as basic research.

The United States could greatly assist the region and reap the political and scientific benefits by working with individual governments to establish a cooperative network of marine science laboratories. The network would serve to provide critical regional information on marine resources and identify problems before they reach crisis proportions.

As we have heard, the regional data collected in this manner will serve to tune the capabilities and sensitivity of the remote sensing technology which provides us the key to deal with the issue of global change that you mentioned at the beginning. Concern for an early warning of change lies at the basis of our interest and concern about phenomena such as coral bleaching. Thank you very much.

[The prepared statement of Dr. John C. Ogden follows:]

Prepared Statement of John C. Ogden, Ph.D.

NETWORKING CARIBBEAN MARINE SCIENCE LABORATORIES TO STUDY REGIONAL PHENOMENA

The Caribbean Sea is a microcosm containing many of the political, economic, and environmental problems of tropical coastal seas everywhere. It is bounded by more than 21 nations and numerous dependencies of Central and South America and of the Greater and Lesser Antilles. The Caribbean, more than any other sea, with the possible exception of the Mediterranean, offers marine scientists a challenge, an opportunity and even an obligation for cooperative international marine research and resource management.

During the next decade, the region will undergo significant changes. Population is exploding and lands are being cleared and developed at an ever-increasing rate. Urbanization and pollution are expected to reduce the quality of coastal waters. Fisheries production in many countries has reached maximal levels or is already over-exploited. Damage and destruction of coastal habitats is epidemic in the region. Poor land-use practices have stripped vegetation from hillsides bordering river basins and destroyed mangrove forests, sending large sediment loads into the coastal zone, smothering seagrass beds and coral reefs offshore. Excessive sedimentation from erosion, dredging, and other sources such as sewage, is perhaps the single greatest impact of man on tropical coasts.

Governments are aware of the lack of information on marine resources but until now they have been reluctant to pool their respective knowledge and address the problems on a regional basis However, through the efforts of the United Nations Educational Scientific and Cultural Organization (UNESCO), the Intergovernmental Oceanographic Commission (IOC), the International Programs of the National Science Foundation (NSF), the political and scientific groundwork has been laid for

international cooperation in marine science and resource management. Marine scientists and marine laboratories in the region have begun networking among themselves to establish procedures that will build an international body of knowledge. One example of such cooperation is the Caribbean Pollution Research and Monitoring Group (CARIPOL) formed as a special venture of the IOC.

A Unified System

The Caribbean measures approximately 500 miles by 1200 miles--a relatively small area--and is swept by the east-west Caribbean Current with coastal counter currents and several large gyres (refer to map). Because most of the marine plants and animals in the region have a planktonic larval phase that lasts for several weeks to more than a year, and the larvae are carried by the currents, the homogeneity of species associations in these waters is striking.

The homogeneity of the Caribbean was dramatized in 1983-84, when a mass mortality killed 95 to 99% of the long-spined black sea urchin (Diadema antillarum) across the Caribbean, as well as Florida, the Bahamas, and Bermuda. Haris Lessios, a biologist at the Smithsonian Tropical Research Institute in Panama, believes the mass mortality was caused by a pathogen (virus, bacterium, fungus, protozoan) as it was species-specific and spread without loss of severity and with remarkable fidelity to the surface current patterns. The disappearance of this abundant plant-eating urchin caused an eruption of algal growth which destroyed corals and other reef-dwelling organisms and changed the appearance and character of Caribbean coral reefs.

Most island and mainland coastlines drop precipitously to deep water within a few miles of shore, and the total area of the coastal zone (to a depth of 200 meters) of the Caribbean is small. Typical of tropical seas, the warm surface waters of the Caribbean lock in nutrient-rich cold waters below. Nutrients, particularly inorganic nitrogen and phosphorous, regenerated from

dead plant and animal material by bacteria, are the fertilizers of plant growth upon which all life depends. Consequently, the rate at which plant material is produced in photosynthesis (primary productivity) of the open sea is low. Most fisheries and renewable marine resources are located in the coastal zone where nutrients are concentrated from other sources and primary productivity is high.

Given its size and the uniformity of distribution of many of its plants and animals, the Caribbean is an ideal natural laboratory to discover the factors which control the distribution and abundance of organisms and those which control the productivity of ecosystems. This basic knowledge can then be generally applied to critical resource management problems.

The Caribbean Coastal Seascape

The coastal seascape of the Caribbean is a complex mosaic of three principal ecosystems: coral reefs, seagrass beds, and mangroves. Distinct in their solutions to the ecological "problem" of obtaining the nutrients lacking in warm surface waters, these tropical marine ecosystems are among the most productive in the world. In terms of biomass production per unit time, they exceed intensively cultivated crops such as sugar cane.

Lush mangrove forests (consisting of several species of trees) are found in river basins, coastal floodplains, and estuaries. In these and other protected areas their root systems collect the abundant nutrients from river discharge and runoff. There appears to be a gradient in the size of mangrove stands in the Caribbean, with the most impressive forests along the coasts of the mainland of Central and South America and the Greater Antilles with their extensive river systems, and a virtual absence of mangroves on the smaller islands of the eastern Caribbean.

Similarly, the most productive seagrass beds (mostly turtle grass, Thalassia testudinum) occur with nutrient enhancement from

runoff or outwelling from coastal mangroves. During times of highest tides and during storms, the nutrients collected in these lagoons get flushed out into the open water, fertilizing the rooted plants growing there. In a gradient that mirrors that of mangrove stand sizes, the seagrass beds become increasingly diverse, with turtle grass decreasing in importance in favor of seagrasses with lower nutrient requirements as one moves from larger to smaller islands.

Unlike mangroves and seagrasses, corals regenerate nutrients internally in association with unicellular algae called zooxanthellae. These intracellular plants require light, hence corals and coral reefs thrive in the nutrient-poor, but clear and clean open ocean waters at the edge of the coastal shelf. The productivity of the coral reef ecosystem also depends upon algal turfs, containing nitrogen-fixing blue-green algae.

Interaction of Caribbean Coastal Ecosystems

The dynamics of nutrient exchange, and other basic aspects of how mangrove, seagrass, and coral reef ecosystems interact in the Caribbean are only now beginning to be understood. The Smithsonian's National Museum of Natural History is helping this effort by sponsoring a regional program of research known as Caribbean Coral Reef Ecosystems (CCRE) headquartered in Belize, but with additional research sites planned for elsewhere in the region.

Coral reefs buffer the impact of the ocean on the coastal zone, creating lagoons and protected waters which favor the growth of seagrasses and mangroves. Mangrove forests and seagrass beds buffer coral reefs from contact with land and promote reef growth offshore by trapping sediments, removing excessive nutrients, and interrupting freshwater discharge, stabilizing the salinity of the coastal zone. Because their environmental requirements are so different, coral reefs and mangroves rarely adjoin one another. However, some of the most

productive coasts are found where broad seagrass meadows are interposed between mangroves and coral reefs.

Coral reefs, seagrasses, and mangroves also interact through daily or seasonal migrations of animals. Judy Meyer, an ecologist at the University of Georgia, found that defecation by schools of reef-dwelling juvenile grunts (Haemulon spp.) by day following nocturnal foraging in nearby seagrass beds increased nutrient concentrations over coral colonies. Corals with resident grunt schools grew faster than those lacking schools.

Seagrass beds and mangroves have been recognized as important nursery areas for many species of reef fishes and invertebrates. Numerous studies at West Indies Laboratory on St. Croix have shown that the planktonic larvae of the commercially important French grunt (Haemulon flavolineatum) preferentially settle in seagrass-covered lagoons where they spend the first few months of their life, moving gradually to coral reefs as small juveniles.

The principal influences on the structure and productivity of the Caribbean coastal seascape are the degree of contact with land, and the complex physical, chemical, and biological interactions between coral reefs, seagrass beds, and mangroves. The mechanisms involved can best be studied along gradients represented by sites where these influences vary. By comparing one site to another over a long period of time, the observed differences and similarities may be correlated with particular factors. Relatively simple measures of community structure and function made over long periods of time along geographical gradients could resolve important pathways of interaction and tell us a great deal about the factors influencing the structure and productivity of coastal communities.

A Cooperative Network of Coastal Marine Laboratories

There are more than 17 marine laboratories within the Caribbean region, many of which have a long tradition of sharing research results. The Association of Island Marine Laboratories

of the Caribbean (AIMLC) with 23 member laboratories including Florida and Bermuda, was founded in 1957 and hosts a meeting at a member laboratory nearly every year. In spite of this relatively high degree of information exchange, studies done at marine laboratories tend to be undertaken in isolation, over relatively short periods of time. Comparison between sites is difficult because usually the studies have differing objectives and use different methods. For this reason, generalizations developed at one site may not apply to other sites.

At several workshop meetings of Caribbean marine scientists held at the West Indies Laboratory in St. Croix and the Discovery Bay Marine Laboratory in Jamaica in 1982 and 1985 under the sponsorship of the National Science Foundation (NSF) and the United Nations Educational, Scientific and Cultural Organization (UNESCO), a program of sustained ecological research was designed involving a cooperating network of Caribbean marine laboratories. The program, called Caribbean Coastal Marine Productivity (CARICOMP), will establish research sites, map the distribution of coral reefs, seagrasses, and mangroves and collect monitoring data using standardized methods and techniques. For example, one of the most simple yet useful measures that integrates many aspects of the environment is the growth rate of principal coral, algae, seagrass, and mangrove species. This information combined with basic physical and chemical data will be centrally processed and incorporated into regional models of coastal productivity.

The developing data base from a number of sites surrounding the Caribbean will suggest patterns which can be intensively examined in specialized research projects. The overall result will be research of a unique regional character directed at an understanding of the factors controlling coastal ecosystem structure and function.

Central to the network is training of Caribbean scientists and technicians in the application of the most modern techniques in marine science including remote sensing, submersibles, ROV's,

and the latest diving technology, exemplified by NOAA's new underwater laboratory, Aquarius. The network will make the best information available to management of marine resources on a regional scale, while stimulating basic research in areas where information is lacking.

Research on Various Time Scales

The network of Caribbean marine laboratories will be able to anticipate and study regional events on short and intermediate time scales, such as mass mortalities, hurricanes, or larval distribution patterns and make real-time maps of rapidly developing events on a region-wide scale.

Mass mortalities of tropical marine animals may be increasing in frequency and involve fishes as well as invertebrates including sea urchins, corals, and sponges. The mortalities may be related to long-term climactic changes or disease. Only a regional program will be able to collect and process data on a large enough geographic and time scale to pin down the causes of these dramatic events.

For example, the bleaching of corals has been most often associated with high temperature such as the long-term cyclic El Nino current that caused coral bleaching and mortality across the tropical Pacific in 1983. One of the most simple measures one can make is temperature, yet there is no program to measure temperature on a regional scale in the Caribbean except from satellites. The satellite imagery is often obscured by clouds, or on too broad a geographic or time scale.

Hurricanes regularly traverse the Caribbean and may be involved in fish kills caused by phytoplankton blooms stimulated by storm-driven upwelling of nutrients from deep water. Hurricanes destroy the dominant coral species on shallow reefs at intervals, opening space that is re-colonized by a variety of species, and promoting biological diversity. The potential for long distance distribution of larvae by currents presently makes identification of fisheries stocks difficult and single point

management of fisheries resources impossible. New techniques involving genetic markers may identify points of origin of larvae and track distribution patterns, providing a rational basis for regional fisheries management.

As an example of an event on a longer time scale, over the past 10 years, "white band disease" of elkhorn coral (Acropora palmata), the principal reef-building coral of the Caribbean, has killed over 90% of this species at Buck Island Reef National Monument in St. Croix, managed by the National Park Service as one of the nation's first underwater parks. The cause of the disease is unknown but it is found through the islands of the eastern Caribbean and may move to mainland coasts to the south and west. The network could rapidly assemble a picture of such events, relate them to micro- and meso-scale circulation patterns, and suggest causes, needed research, and management strategies.

On a still longer time scale, sea level is projected to rise rapidly over the next 100 years, potentially interfering with the wave buffering capacity of coral reefs on the coastal zone. A systematic program of coral cores at the network sites will help define the climatic factors and events that have led to the establishment and growth of coral reefs in the Caribbean. Corals have growth rings which can be used just like tree growth rings to infer past conditions. Good baseline data will be needed to track sea level, look at the growth responses of coral reefs, and anticipate management problems associated with increased wave action in the coastal zone. A coral coring program directed by Peter Isdale at the Australian Institute of Marine Science tracked the influence of river flow over the past few hundred years on coral and reef growth.

The Role of the United States

The Caribbean region lies on our back doorstep, yet has been too easily ignored. Other countries such as the Soviet Union, Canada, and Cuba have eclipsed the involvement of the U.S. in

marine resources and development problems in the region. The political and scientific basis for regional cooperation already exists. The U.S. could greatly assist the region and reap the political benefits, by working with individual governments to establish a cooperative network of marine science laboratories. Through this network, the most modern tools of oceanography, including satellite imagery, could be applied to critical problems of marine resource development and management. The network would train young scientists and technicians within the countries involved. Research of a unique regional character would be the result.

The network of marine laboratories would serve to provide "ground truth" for the new technology being applied to study global change. Data gathered in a coordinated regional program could be used to tune the capabilities and sensitivity of remote sensing technology and will provide the key to linking the past with the future in our understanding of the tropical coastal zone.

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This statement is adapted from an article by the author in the December 1987 issue of OCEANUS devoted to marine science in the Caribbean Sea and published by the Woods Hole Oceanographic Institution. The contribution of the Steering Committee of the Caribbean Coastal Marine Productivity (CARICOMP) program, the NSF, and the UNESCO COMAR program is gratefully acknowledged.

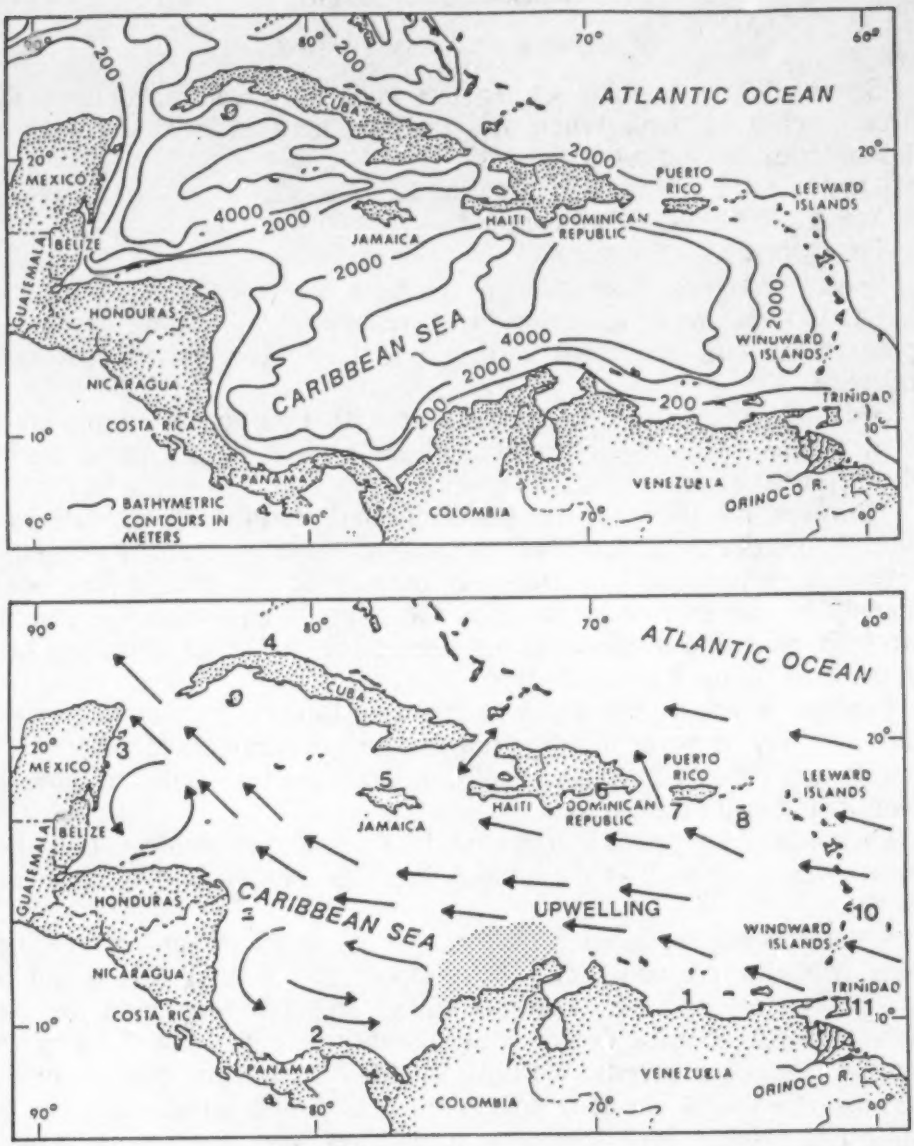

FIGURE 1: Maps of the Caribbean Sea showing bathymetric contours (top) and current patterns (bottom). The numbers (bottom) refer to the tentative CARICOMP research sites.

General Questioning

Regional Program Funding

Senator Weicker. John, let me start with you. I want anybody to feel free to chip in here. When you say this network, what network of laboratories are you talking about?

Dr. Ogden. Existing coastal marine laboratories.

Senator Weicker. Of all nations?

Dr. Ogden. Of all nations.

Senator Weicker. You say there has been resistance?

Dr. Ogden. Well, there has been resistance to funding a regional program as our traditional approach to Caribbean nations has been bilateral.

We can easily strike up a relationship with a particular country to do a particular job, let's say, a mariculture project, or a coastal marine development effort.

However, the Caribbean is politically and environmentally complex, with 17 bordering nations, and getting all these governments together seems overwhelming. I can tell you, because of the linkage established already by the marine laboratories the political and scientific groundwork for scientific cooperation has been done, and what is lacking here is the funding for a retional effort.

Senator Weicker. But my problem, as I listened to everybody's testimony today, is never mind getting all our governments together; I am not so sure that we have got all of our own agencies within this government together on the project.

Dr. Ogden. I suppose that is true. In a sense, our problem in a complex government such as the United States' is communication and teamwork.

Senator Weicker. I am a little bit, and I think if Senator Hollings were here, he too would be a bit disappointed. I think this would be the best word, because Senator Hollings and I have carried the ball here for nigh on to a decade now to make sure that the funding for marine research proceeds. We have shielded it from the cuts of several administrations. Maybe it is not as much as people would like, but on the other hand, it has been present, and yet what bothers me now is when we are confronted with a particular crisis, I really have nobody able to give me an answer or even tell me that the mechanism is in place to give me an answer.

Indeed, Dr. Carpenter talked about a short-term phenomenon, how do we address it? As he says, results were taken in isolation so he called for an integrated Caribbean effort. John, you called for one as far as the various governments are concerned.

I realize I haven't had as much to do with the National Science Foundation, but certainly everybody else here has been discussing whether this deals with Marine Fisheries Service or, NOAA, or NURP, or whatever. Yet really, what I am being told is that there is nobody I can turn to to get an answer.

Dr. OGDEN. There are two aspects to that I would like to address and then I will stop talking. First of all, we have to be impressed at the speed with which this happened. We are talking about an event that started in mid-September and is going on now. In fact, thanks to you and Senator Hollings we are remarkably organized.

This hearing is very significant in terms of the perception of the United States in the Caribbean. Second, there has been a considerable amount of regional marine resources planning effort by NOAA; by AID; by the National Academy of Sciences, and so on, laying, the groundwork for regional cooperation.

I am very hopeful that we are ready to approach the scientific management of the Caribbean.

MULTIPLE PROBLEMS IN CARIBBEAN AREA

Senator WEICKER. But I have got to point out, that just at this hearing alone, I heard about something new. I didn't know about the elkhorn coral phenomenon. We don't have an answer to it. We still don't have an answer to the Diadema situation, which I raised at hearings several years ago. Now we have this latest event here.

I mean, I think it is great to be informed that these things are going on, but I also would like to believe that somebody has got a handle on them and is at least striving for an answer.

Dr. OGDEN. That is right.

Senator WEICKER. I am not so sure that I know of anybody in particular. Who do I turn to if I want an answer? That is really what I am looking for.

This hearing has been very useful to me. I fully intend to have NOAA's people in so that we can get something structured so that we don't have to have hearings or have everybody de facto getting together in an organization every time there's a crisis.

Dr. D'ELIA. Senator, may I jump in for a second?

Senator WEICKER. You sure may; anybody may jump in.

Dr. D'ELIA. I have two comments. I want to say that we do have a program at NSF for rapid response for proposals under $20,000, and Dr. Carpenter may feel free to submit a proposal to us. We can make a decision in several weeks. We are prepared for that sort of thing. We don't have large amounts of money to devote to rapid response, because we don't have large amounts of money, but we are prepared to review such proposals quickly.

We can evaluate a proposal as best as possible within the constraints we have to deal with. We support that program very, very strongly.

I would like to point out that many of the scientific facts you heard today have been discovered because of research supported by organizations like the Foundation—organizations that support basic research. I think that basic research needs very strong support in this country, and I am concerned about the overall support of basic research.

Senator WEICKER. I think you know the tremendous support. I give to basic research, but I do in medicine and everything else. I agree with you. You have no argument from me on that one at all.

I wish this nation knew the dedication which all of you have given to this country in pursuit of your disciplines. Were it not for that dedication, we wouldn't even have the knowledge we have got now. God knows there hasn't been that many millions of dollars afforded to your work. I want recognition given to all of you.

I don't want my remarks to be taken to mean that you have not accomplished just tremendous leaps of knowledge with really very little money compared to what other people get from Uncle Sam. My problem right now, though, is to make sure that we somehow get a structure to this thing so that when we are confronted with a crisis in the future we have a way to go. That is the only thing that I think is really open to question at this juncture.

I think it has been expressed by several of the witnesses here. I sure get a feeling for it, I can tell you that. I am delighted, for example, with your offer, Dr. D'Elia. What do I do with your offer? In the sense that I think it would be useful, obviously, if somebody did something. It really ought to be done, and I know NSF does its thing, but it would be foolish to have NSF do its thing without NOAA understanding what it is that NSF is doing. We don't want to have duplication here or all the ships passing in the night with respect to the information gained.

Dr. D'ELIA. We do make considerable attempts to coordinate with other agencies. There is no question about that. I spend a lot of my time attending to interagency matters, but mostly for longer-term programs. I mentioned the Global Geosciences Program in NSF and programs like TOGA, which really do relate, I think, very strongly to what we are talking about here.

There is a massive effort to try to coordinate our activities, and it is a complicated thing, but we are doing it.

The problem comes in when you have a sudden, unexpected event and you want to mobilize support immediately. It is not easy to do. As you know, in these situations, it is not easy to develop budgets in the long term. That is part of the problem.

Senator WEICKER. Walter?

ADMINISTRATIVE PROBLEMS IN FLORIDA

Mr. JAAP. I have just a statement to make. I would like to focus more on our own backyard, which is what I do in Florida. We have a real problem down there with administration. It is fragmented.

If you look at the Australian model, the Queensland Government and the Commonwealth Government have combined to form a Great Barrier Reef Park Authority. They have total control and management of that reef system off the coast of Queensland.

They cooperated and agree, and there is not this fragmentation with 15 different agencies arguing as to who is going to do what. In Florida, up until about 1937, we had a fairly substantial marine laboratory at Loggerhead Key. It burned down. Nothing has been replaced. At this time and place, there is only a few facilities in Florida where you can really manage research expeditions or any kind of long-term program

down there, sea camp and that sort of thing. Marine Sanctuaries programs have some offices down there, but there really isn't a decent lab, and as a result, we suffer quite a bit down there because there is a lack of a real program and a real management effort on a national basis.

I put that in my comments, and I gave a model on the Australian thing. I wish that we could get together sometime and get that ironed out.

Senator WEICKER. If you want to draw the analogy, there is really very little difference in what I have seen from the maps that have been presented between the Great Barrier Reef in Australia and the entire Caribbean. They are one resource, if you will, and probably appropriately ought to be addressed as such.

Mr. JAAP. I think it is ridiculous to have a line 3 miles off the coast of Florida and say everything at that line is the responsibility of this agency and everything to left of that line is the responsibility of this agency. The organisms move back and forth across that line. The water processes move back and forth across that line. There is absolutely no difference.

To say the Federal Government is going to manage this part of it and the State is going to manage this part of it is crazy.

Dr. DILL. One of the problems is that the organisms don't have to get funded. Scientists do. If you are a successful marine scientist, you have to be a funded scientist. You can't go it out on your own. The days of working up to your knees and going after these are impossible; just getting funding to come here, for instance, to talk, making telephone calls. If you are a scientist, we get together.

We know what is going on. We work together, but we need to have some means by which we get funds into this so that we can do it in a proper manner. That is really our problem.

Now, I think you put your finger on it very nicely. You say, "NOAA, I would like very much to have you look into this particular program." They are going to respond; they are going to respond real fast. They like the way you tell them to do things. [Laughter.]

Dr. DILL. I honestly know, after 32 years, in a month, I have that feeling. I think that this is the way we are going to get it done, and I think this hearing is extremely valuable; that what you have been here is something that happened really in September. Here we are at the very beginning of November. We are actually almost in the middle of November it has gone by so fast, but that is remarkable to be able to put this together. And we have the people in place; we can go ahead and do these things that John has pointed out.

The Caribbean Marine Laboratory. They have been there for a long time. There are people down there who want to work on it. I had at least six people call me this last week saying, "Don't forget to tell them about—I wanted to work on this thing, too, because I think it is extremely important."

But we need to get together to find out what we are going to work on and what our objectives are going to be at the other end of it. Because we are going to spend some money.

ST. CROIX CONFERENCE

Senator WEICKER. What is this conference down in St. Croix? Who is coming to that?

Dr. CARPENTER. The Science Directors and Principal Investigators of the National Undersea Research Programs and Directors from selected Caribbean laboratories.

Dr. OGDEN. We haven't got a guest list of the laboratories yet.

Senator WEICKER. Who is involved with that? Are other nations involved with it?

Mr. DUANE. Sure.

Senator WEICKER. Do they have private, and when I say private, I mean laboratories outside of government?

Dr. OGDEN. Within individual Caribbean countries, sometimes these laboratories are government laboratories.

Senator WEICKER. I am not talking about the foreign ones. I am talking about our own, now. Who is coming from the United States, various university laboratories. Are NOAA and NSF going to be there?

Dr. D'ELIA. I doubt it.

Senator WEICKER. I think maybe.

Mr. DUANE. Senator, we haven't finalized the list yet.

Senator WEICKER. Maybe somebody ought to be invited down from NSF. It is not——

Mr. DUANE. Yes.

Senator WEICKER. It is not too great a hardship to go there. NSF, NOAA, Sea Grant will have some representatives there.

Dr. DILL. The problem here is that there will be people who have not been invited to that particular program that are participating and have a significant——

Senator WEICKER. What I am suggesting here is that this conference happens just by luck to be set up. You just might expand your guest list a little bit rather than calling a whole separate conference. Let's go there and talk about it and see what comes of it. I think it is an ideal opportunity.

IMPORTANCE OF BASIC RESEARCH

Dr. CARPENTER. Senator, if I may interject here, I would like to echo something that Dr. D'Elia mentioned about the importance of basic research. What I see here is dichotomy. We are focusing on crisis management now, but underlying the whole problem of our inability to understand why these things happen is our basic lack of understanding of these complex systems, as I mentioned.

That has a long history, and I think yourself and Senator Hollings have certainly been instrumental in supporting ocean sciences for a long while. However, if we compare that to other sciences, we are way behind. We have a lot of ground to make up.

I think what we need to be doing is not taking the whole approach in one direction. We want to make sure it is a balanced approach of maintaining support for on-going basic and applied research. I would point out that several of the missions, the upcoming saturation missions using our facilities, will be addressing aspects of coral metabolism, and although not directly relevant to the bleaching event, will provide us with the underlying information that can help us understand this.

Senator WEICKER. You will have no argument out of me as to the essential nature of basic research. As you may or may not know, probably nobody has been out on that front longer, has more scars to show for it on behalf of the National Institutes of Health than I have, and for all the good ridiculing of basic research that comes forth from some of my colleagues from time-to-time, that is where it all starts.

Indeed, the best example I can give within everybody's knowledge is that the only reason why we are as far ahead on the AIDS problem as we are is all of the basic research that preceded it. Research at the Cancer Institute, and other institutes all of a sudden came together when confronted with this new problem. You are not going to get any argument out of me. I agree that the funding as far as basic research has been way behind that of space and the National Institutes of Health and whatever. It is important. We will not forget that.

But we have got an immediate problem here, now, that has got to be addressed. I really want to get a handle on it as best as I can, because I think we are still confronted with things going on in the system that are not being explained. After each we are just moving on to the next square.

MAJOR EVENTS IN CARIBBEAN

I think we better catch up with ourselves now. We have got three rather major events just in this body of water. Assuming the fact there is no connection between the Caribbean and the situations further up the coast. I mean, I think it is not enough to just read about it. It is not enough to just have hearings about it. I think we are at least owed at some point an explanation, and there is no reason why we shouldn't be able to get that explanation with a concentrated effort.

Knowledge is certainly there. Unfortunately, for better or for worse, I don't like to pull all things under one head. I think the scientific community really does better being free to operate its own way. But there has got to be some pulling together of knowledge once it has been gained.

Also, I think I know the characteristics of your community. You know, you are all a bunch of free booters. You like to do your own thing, and that is fine, but then all of a sudden something happens, and for all I know, the knowledge may well be out there right now to explain what has happened.

But there is no clearinghouse, none whatsoever. Maybe we need at NOAA the same type of thing that we have over at NIH, which is the Library of Medicine. That is the clearinghouse, where anybody can dial into the system and find out what it is that some researcher out in

Seattle is doing or has discovered. I don't know. But something, in other words, where there is a clearinghouse for this type of information, which might have helped get at this particular problem.

As I say, we have got a fortunate event taking place. Maybe we can at least communicate there. Coming up in the first week of December, the seminar in St. Croix will give us something to pull together on, not just for the habitat itself, but also for the dissemination of information about the coral bleaching event.

In any event, I thank you all for telling me what it is that we don't know. [Laughter.]

CONCLUDING REMARKS

Senator WEICKER. I think what we ought to do, since we all worked so well together in the past, is to get the answers. It is worrying to me. I just don't believe that all these things are disassociated. I really don't. If we do our job just to anticipate what might lie out there, this is the time to go ahead and do it.

Your remarks will be included in their entirety in the record. Is there anything that anybody that is here wants to submit to the committee or any statement that anybody has to make which has not been heard?

I thank you all for your attendance, and the committee will stand in recess. Bob?

Mr. WICKLUND. A couple of days ago a friend of mine told me that he has found out that there are a lot of strange things happening in the ocean in different places. He told me that New Jersey has exceptionally clear water this year, and that's something to worry about. [Laughter.]

Mr. WICKLUND. It is all tied together some way.

CONCLUSION OF HEARING

Senator WEICKER. Governor Kean will love to hear your remark. All right. Thank you all very much. The hearing is concluded, and the subcommittee will stand in recess.

[Whereupon, at 11:59 a.m., Tuesday, November 10, the hearing was concluded, and the subcommittee was recessed, to reconvene at the call of the Chair.]

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